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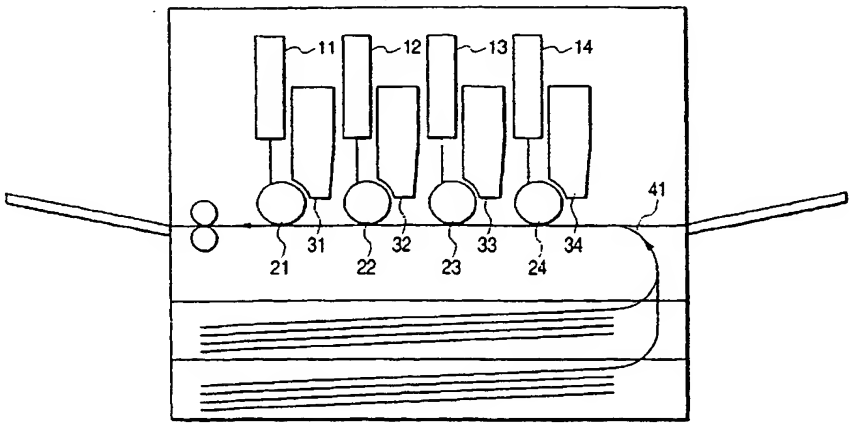
(54) Scanning optical device and image forming apparatus

(57) As has been described above, this invention can achieve a scanning optical device and color image forming apparatus in which a refraction element and diffraction element are used as the scanning optical element of a scanning optical device, the powers of the refraction element and diffraction element are set such that an imaging position deviation in the main scanning direction caused by a wavelength variation along with the environmental fluctuation of the scanning optical device and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of an effective image region (effective scanning region), thereby reducing an imaging position deviation caused by an environmental fluctuation, and at the same time an imaging position deviation caused by a wavelength variation not accompanied by any environmental fluctuation is also set to a desired value or less, thereby implementing a scanning optical device resistant to a wavelength fluctuation or environmental fluctuation, and in which images are recorded on a plurality of image carriers (photosensitive drums) using a plurality of scanning optical devices, thereby implementing with a simple arrangement at low cost a color image forming apparatus which is almost free from misregistration between colors caused by a wavelength fluctuation or environmental fluctuation and almost free from density nonuniformity between colors.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a scanning optical device and image forming apparatus and, more particularly, to a compact image forming apparatus suitable for high-resolution printing with, e.g., a color electrophotographic process, such as a laser beam printer (LBP) or color digital copying machine, in which an imaging position variation caused by the wavelength fluctuation of a light source means, an aberration variation upon an environmental fluctuation, and the like in each scanning optical device are compensated by a compensation means in a color image forming apparatus having a plurality of scanning optical devices, thereby suppressing an imaging position deviation in especially the main scanning direction, and reducing color misregistration, and image density nonuniformity at low cost with a simple arrangement.

Related Background Art

[0002] Conventionally in a scanning optical device used in an image forming apparatus such as a laser beam printer or digital copying machine, a beam modulated and emitted by a light source means in accordance with an image signal is periodically deflected by an optical deflector formed from, e.g., a rotary polyhedral mirror (polygon mirror), and converged into a spot on a photosensitive recording medium (photosensitive drum) surface by an imaging optical system (scanning optical system) having an f-θ characteristic. This surface is optically scanned to record an image.

[0003] Fig. 24 is a schematic view showing the main part of a conventional scanning optical device.

[0004] In Fig. 24, a divergent beam emitted by a light source means 91 is converted into a nearly collimated beam by a collimator lens 92. The beam is limited by a stop 93, and enters a cylindrical lens 94 having a predetermined refracting power in only the sub scanning direction. Of the nearly collimated beam that enters the cylindrical lens 94, light components in the main scanning plane directly emerge as a nearly collimated beam. In the sub scanning plane, light components are converged to form an almost line image on a deflection surface (reflection surface) 95a of an optical deflector 95 formed from a rotary polyhedral mirror (polygon mirror).

[0005] The beam deflected and reflected by the deflection surface 95a of the optical deflector 95 is guided onto a photosensitive drum surface 98 as a surface to be scanned via an imaging optical element (f-θ lens) 96 having f-θ characteristics. By rotating the optical deflector 95 in a direction indicated by an arrow A, the beam scans the photosensitive drum surface 98 in a direction indicated by an arrow B to record image information.

[0006] Fig. 25 is a schematic view showing the main part of a conventional color image forming apparatus. In Fig. 25, the color image forming apparatus simultaneously uses a plurality of scanning optical devices 111 to 114 like the above-described one to record pieces of image information of respective colors on corresponding photosensitive drums 121 to 124, thereby forming a color image. In this color image forming apparatus, it is important to reduce not only an imaging position deviation represented by jitter of a single color but also scanning line deviations (to be referred to as "misregistration" hereinafter) between colors, and image density nonuniformity between colors in order to align a plurality of scanning lines and form an image. For this purpose, the scanning optical device must satisfy the following conditions.

(1) An imaging position variation (spot position deviation) in the main scanning direction along with the wavelength fluctuation of a beam emitted by a semiconductor laser serving as a light source (to be simply referred to as the "wavelength fluctuation of the semiconductor laser" hereinafter) is compensated.

(2) A focus variation in the sub scanning direction along with an environmental fluctuation such as influential temperature elevation is compensated (a focus variation in the main scanning direction is originally small and does not pose any problem in many cases).

(3) An imaging position deviation in the main scanning direction along with an environmental fluctuation such as temperature elevation is small.

(4) An imaging position deviation in the main scanning direction caused by a wavelength variation (not accompanied by any environmental fluctuation) is small.

The image forming apparatus requires not only stable optical performance in one scanning optical device (single color) but also an arrangement which can prevent misregistration or image nonuniformity between colors even when the light source wavelength (wavelength of a beam emitted by the light source), initial wavelength, or use environment (particularly ambient temperature) of the scanning optical device fluctuates, or even when the light source wavelengths, initial wavelengths, or use environments of a plurality of scanning optical devices differ.

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[0007] Further, when such a color image forming apparatus uses a light source having a plurality of light-emitting portions represented by multi-beam lasers (e.g., multi-semiconductor lasers), jitter by a plurality of beams (scanning interval fluctuation in the main scanning direction on the photosensitive drum surface) occurs owing to the wavelength difference between the light-emitting portions, greatly degrading the image quality. To prevent this, (1) compensation of a spot position deviation and (4) compensation of a spot imaging position deviation not accompanied by any environmental fluctuation become more important.

[0008] Such a scanning optical device has conventionally used a glass lens or glass mirror which hardly exhibits a characteristic fluctuation caused by an environmental fluctuation. However, an aberration variation caused by the wavelength fluctuation of a semiconductor laser remains, advanced aberration correction by an aspherical surface cannot be performed, and the cost is high. Thus, demands have arisen for compensation of a wavelength fluctuation, environmental fluctuation, or the like by a scanning optical device using a plastic material.

[0009] Japanese Patent Application Laid-Open No. 3-231218 discloses a scanning optical device in which a scanning optical system is constituted by a glass spherical lens and plastic toric lens. In this reference, an imaging position deviation in the main scanning direction caused by a wavelength variation of 5 nm is 64.6 μm, and a focus deviation in the sub scanning direction at a temperature elevated by 25°C is +1.7 mm. For example, a color image forming apparatus using a plurality of such scanning optical devices suffers misregistration or image nonuniformity between colors.

[0010] Japanese Patent Application Laid-Open No. 7-128603 discloses an example in which a glass lens and glass cylinder mirror are used as the scanning optical system of a scanning optical device used in a color image forming apparatus. In this reference, all the scanning optical systems are made of a glass material. An aberration variation caused by the wavelength fluctuation of a semiconductor laser remains. Aberration correction by an aspherical surface cannot be performed, so the optical path is long. In addition, the cost is high.

[0011] Japanese Patent Application Laid-Open No. 10-232347 discloses an example in which a scanning optical system is formed from two toric lenses. In this reference, all the scanning optical systems are made of a plastic, which is advantageous for aberration correction. However, the laser wavelength increases as the temperature is elevated. When the refractive index of the scanning optical system decreases, the laser wavelength varies in a direction in which the focal length of a scanning lens increases. As a result, the imaging position in the main scanning direction greatly deviates.

[0012] It is an object of the present invention to provide a compact scanning optical device and color image forming apparatus suitable for high-resolution printing in which an imaging position variation caused by the wavelength fluctuation of a light source means, an aberration variation upon an environmental fluctuation, and the like in each scanning optical device are compensated by a compensation means (third optical element) in a color image forming apparatus having a plurality of scanning optical devices, thereby suppressing an imaging position deviation in especially the main scanning direction, and reducing color misregistration and image density nonuniformity at low cost with a simple arrangement.

[0013] It is another object of the present invention to provide a scanning optical device and color image forming apparatus suitable for high-resolution printing in which an aberration variation accompanied by the environmental fluctuation of each scanning optical device and an aberration variation not accompanied by any environmental fluctuation are suppressed in a color image forming apparatus having a plurality of scanning optical devices, thereby reducing color misregistration and image density nonuniformity at low cost with a simple arrangement.

SUMMARY OF THE INVENTION

[0014] According to one aspect of the invention, a scanning optical device comprises light source means, and an optical element having a refraction element and a diffraction element,

wherein powers of said refraction element and said diffraction element are set such that an imaging position deviation in a main scanning direction on a surface to be scanned that is caused by a wavelength variation of a beam emitted by said light source means along with an environmental fluctuation of said scanning optical device, and an imaging position deviation in the main scanning direction on the surface to be scanned that is caused by a refractive index variation of a material of said optical element along with an environmental fluctuation are set to be in opposite directions at two ends of an effective scanning region.

[0015] According to further aspect of the invention, said optical element includes an element which forms the beam emitted by said light source means into an image on the surface to be scanned, and letting ϕLm and ϕDm be powers of said refraction element and diffraction element constituting said optical element in the main scanning direction, and νL be an Abbe number of a material of said refraction element, the powers satisfy a condition:

$$\nu L/6.90 \leq \phi Lm/\phi Dm \leq \nu L/3.45$$

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[0016] According to further aspect of the invention, an imaging position variation per unit mode hopping of said light source means is not more than 3 μm at the two ends of the effective scanning region.

[0017] According to further aspect of the invention, a focus position deviation in a sub scanning direction on the surface to be scanned that is caused by the wavelength variation of the beam emitted by said light source means along with the environmental fluctuation, and a focus position deviation in the sub scanning direction on the surface to be scanned that is caused by the refractive index variation of the material of said optical element along with the environmental fluctuation are substantially compensated within the effective scanning region.

[0018] According to further aspect of the invention, the environmental fluctuation includes an atmospheric variation of said scanning optical device and a temperature variation caused by self-temperature elevation.

[0019] According to further aspect of the invention, said refraction element includes a toric lens, and said diffraction element includes a composite optical element obtained by integrating a refraction surface and a diffraction surface.

[0020] According to further aspect of the invention, said refraction element and diffraction element constituting said optical element are formed from a plastic material.

[0021] According to further aspect of the invention, said light source means includes a multi-beam laser source having a plurality of light-emitting portions.

[0022] According to further aspect of the invention, letting ϕLs and ϕDs be powers of said refraction element and diffraction element constituting said optical element in a sub scanning direction, the powers satisfy a condition:

$$1.0 \leq \phi Ls/\phi Ds \leq 2.6$$

[0023] According to further aspect of the invention, the powers of said refraction element and said diffraction element are set to compensate for an imaging position variation in the main scanning direction on the surface to be scanned that is caused by a wavelength fluctuation of the beam emitted by said light source means.

[0024] According to one aspect of the invention, an image forming apparatus comprises a plurality of pairs of scanning optical devices defined in claim 1 and corresponding image carriers, guides beams emitted by said scanning optical devices to corresponding image carriers, scans surfaces of said image carriers to form images of different colors on the surfaces of said image carriers, and forms a color image by the images formed on the surfaces of said image carriers.

[0025] According to one aspect of the invention, a scanning optical device guides a beam emitted by light source means to a surface to be scanned, and scans the surface with the beam,

wherein said scanning optical device comprises compensation means having a refraction element and a diffraction element so as to compensate for an imaging position deviation in a main scanning direction on the surface to be scanned that is caused by a wavelength fluctuation of the beam emitted by said light source means, and

letting ϕLm and ϕDm be powers of said refraction element and said diffraction element in the main scanning direction, the powers satisfy a condition:

$$5.8 \leq \phi Lm/\phi Dm \leq 20$$

[0026] According to further aspect of the invention, a focus position variation in a sub scanning direction on the surface to be scanned that is caused by an environmental fluctuation of said scanning optical device is compensated by power variations of said refraction element and said diffraction element, and a wavelength variation of the beam emitted by said light source means.

[0027] According to further aspect of the invention, said refraction element is formed from a plastic material.

[0028] According to further aspect of the invention, said compensation means includes means for forming the beam emitted by said light source means into an image on the surface to be scanned.

[0029] According to further aspect of the invention, said light source means includes a multi-beam laser source having a plurality of light-emitting portions.

[0030] According to further aspect of the invention, said compensation means includes means for compensating for an imaging position variation in the main scanning direction on the surface to be scanned that is caused by the wavelength fluctuation of the beam emitted by said light source means, and a scanning interval fluctuation in the main scanning direction on the surface to be scanned that is caused by a wavelength difference between beams emitted by a plurality of light-emitting portions.

[0031] According to one aspect of the invention, an image forming apparatus comprises a plurality of pairs of scanning optical devices set out in the foregoing and corresponding image carriers, guides beams emitted by said scanning optical devices to corresponding image carriers, scans surfaces of said image carriers to form images of different colors on the surfaces of said image carriers, and forms a color image by the images formed on the surfaces of said image carriers.

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[0032] According to one aspect of the invention, an image forming apparatus comprises a scanning optical device set out in the foregoing and a printer controller for converting code data input from an external device into an image signal and inputting the converted image signal to said scanning optical device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033]

Fig. 1 is a schematic view showing the main part of a color image forming apparatus according to the first embodiment of the present invention;
Fig. 2 is a schematic view showing the main part of a scanning optical device shown in Fig. 1 and a corresponding image carrier;
Fig. 3 is a sectional view showing the main part of an optical system shown in Fig. 2 in the main scanning direction;
Fig. 4 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the first embodiment of the present invention;
Fig. 5 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the first embodiment of the present invention;
Fig. 6 is a sectional view showing the main part of the optical system of a scanning optical device constituting a color image forming apparatus in the main scanning direction according to the second embodiment of the present invention;
Fig. 7 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the second embodiment of the present invention;
Fig. 8 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the second embodiment of the present invention;
Fig. 9 is a sectional view showing the main part of the optical system of a scanning optical device constituting a color image forming apparatus in the main scanning direction according to the third embodiment of the present invention;
Fig. 10 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the third embodiment of the present invention;
Fig. 11 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the third embodiment of the present invention;
Fig. 12 is a sectional view showing the main part of the optical system of a scanning optical device constituting a color image forming apparatus in the main scanning direction according to the fourth embodiment of the present invention;
Fig. 13 is a graph showing the imaging position deviation of the most off-axis beam caused by temperature elevation in the fourth embodiment of the present invention;
Fig. 14 is a graph showing the imaging position deviation of the most off-axis beam upon a wavelength variation not accompanied by temperature elevation in the fourth embodiment of the present invention;
Fig. 15 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the fourth embodiment of the present invention;
Fig. 16 is a sectional view showing the main part of the optical system of a scanning optical device constituting a color image forming apparatus in the main scanning direction according to the fifth embodiment of the present invention;
Fig. 17 is a graph showing the imaging position deviation of the most off-axis beam caused by temperature elevation in the fifth embodiment of the present invention;
Fig. 18 is a graph showing the imaging position deviation of the most off-axis beam upon a wavelength variation not accompanied by temperature elevation in the fifth embodiment of the present invention;
Fig. 19 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the fifth embodiment of the present invention;
Fig. 20 is a sectional view showing the main part of the optical system of a scanning optical device constituting a color image forming apparatus in the main scanning direction according to the sixth embodiment of the present invention;
Fig. 21 is a graph showing the imaging position deviation of the most off-axis beam caused by temperature elevation in the sixth embodiment of the present invention;
Fig. 22 is a graph showing the imaging position deviation of the most off-axis beam upon a wavelength variation not accompanied by temperature elevation in the sixth embodiment of the present invention;
Fig. 23 is a graph showing an imaging position variation in the main scanning direction caused by a wavelength variation in the sixth embodiment of the present invention;

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Fig. 24 is a sectional view showing the main part of a conventional scanning optical device in the main scanning direction;

Fig. 25 is a schematic view showing the main part of a conventional color image forming apparatus; and

Fig. 26 is a schematic view showing an image forming apparatus according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[First Embodiment]

[0034] Fig. 1 is a schematic view showing the main part of a color image forming apparatus according to the first embodiment of the present invention.

[0035] In Fig. 1, scanning optical devices 11, 12, 13, and 14, photosensitive drums 21, 22, 23, and 24 serving as image carriers, and developing units 31, 32, 33, and 34 are arranged along a convey belt 41. In the color image forming apparatus of the first embodiment, as will be described below, the four scanning optical devices (11, 12, 13, and 14) in which an imaging position variation caused by the wavelength fluctuation of a beam emitted by a light source (to be simply referred to as the "wavelength fluctuation of the light source" hereinafter) or an aberration variation upon an environmental variation (temperature variation) are arranged, respectively correspond to four, C (Cyan), M (Magenta), Y (Yellow), and B (Black) colors, and record image signals (image information) on the surfaces of the photosensitive drums 21, 22, 23, and 24 in parallel with each other, thereby printing a color image at a high speed.

[0036] A method of appropriately correcting an imaging position variation caused by the wavelength fluctuation of a light source or an aberration variation upon an environmental fluctuation, which is a characteristic feature of the present invention, and an optical element therefor will be explained.

[0037] Fig. 2 is a schematic view showing the main part of one scanning optical device and a corresponding image carrier, and Fig. 3 is a sectional view (sectional view of main scanning) showing the main part of the optical system shown in Fig. 2 in the main scanning direction.

[0038] In Figs. 2 and 3, a light source means (laser source) 1 is formed from, e.g., a semiconductor laser. A collimator lens 2 serving as a first optical element converts a divergent beam emitted by the light source means 1 into a nearly collimated beam. An aperture stop 3 limits a passing beam (light quantity). A cylindrical lens (cylinder lens) 4 serving as a second optical element has a predetermined refracting power in only the sub scanning direction, and forms the beam having passed through the aperture stop 3 into an almost line image on a deflection surface (reflection surface) 5a of an optical deflector 5 (to be described later).

[0039] The optical deflector 5 serving as a deflection element is formed from, e.g., a polygon mirror (rotary polyhedral mirror), and rotated by a driving means (not shown) such as a motor at a predetermined speed in a direction indicated by an arrow A in Fig. 2.

[0040] A scanning optical element 6 as a third optical element (compensation means) having an f-θ characteristic has a refraction element 61 and diffraction element 62. The refraction element 61 is formed from a single plastic toric lens having different powers in the main scanning direction and sub scanning direction. Two lens surfaces 61a and 61b of the toric lens 61 in the main scanning direction are aspherical.

[0041] The diffraction element 62 is formed from an elongated composite optical element having different powers in the main scanning direction and sub scanning direction. An incident-side surface 62a of the composite optical element 62 is an aspherical surface having a predetermined power in only the main scanning direction (surface in the sub scanning direction is flat), whereas an exit-side surface 62b is a diffraction surface with a diffraction grating 81 added to a flat surface. The grating shape of the diffraction grating 81 is preferably a Fresnel grating shape of a sawtooth-like diffraction grating by surface cutting, or a stepped diffraction grating shape by photoetching. The composite optical element 62 in this embodiment is made of a plastic prepared by injection molding. The same effects can also be obtained by forming a diffraction grating from a replica on a glass substrate.

[0042] In the first embodiment, the toric lens 61 is disposed on the polygon mirror 5 side with respect to the midpoint between the rotating shaft of the polygon mirror 5 and a surface 8 to be scanned, and the composite optical element 62 is disposed on the surface 8 side. Each optical element has different powers in the main scanning direction and sub scanning direction, as described above. These optical elements form a deflected beam from the polygon mirror 5 into an image on the surface 8, and correct the face tangle error of the deflection surface of the polygon mirror. The surface 8 to be scanned is a photosensitive drum surface.

[0043] The color image forming apparatus in this embodiment forms latent images on the surfaces of the corresponding photosensitive drums 21, 22, 23, and 24 by the four scanning optical devices 11, 12, 13, and 14 using beams based on modulated signals. For example, the color image forming apparatus forms C (Cyan), M (Magenta), Y (Yellow), and B (Black) latent images on the surfaces of the corresponding photosensitive drums 21, 22, 23, and 24, and multiple-transfers the latent images on a recording medium to form one full-color image.

[0044] In the scanning optical device of this embodiment, a divergent beam emitted by the semiconductor laser 1 is

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converted into a nearly collimated beam by the collimator lens 2. The beam (light quantity) is limited by the aperture stop, and enters the cylindrical lens 4. Of the nearly collimated beam that enters the cylindrical lens 4, light components in the main scanning section directly emerge as a nearly collimated beam. In the sub scanning section, light components are converged to form an almost line image (elongated line image in the main scanning direction) on the deflection surface 5a of the optical deflector 5. The beam deflected by the deflection surface 5a of the optical deflector 5 is guided onto the photosensitive drum surface 8 via the toric lens 61 and composite optical element 62. By rotating the optical deflector 5 in a direction indicated by an arrow A, the beam scans the photosensitive drum surface 8 in a direction indicated by an arrow B (main scanning direction). As described above, e.g., C (Cyan), M (Magenta), Y (Yellow), and B (Black) latent images are formed on the surfaces of the corresponding photosensitive drums 21, 22, 23, and 24, and multiple-transferred to a recording medium to form one full-color image.

[0045] The toric lens 61 and composite optical element 62 which constitute the third optical element (scanning optical element) 6 of the scanning optical device in the first embodiment have the following shapes.

- Refraction surface ... aspherical shape whose main scanning direction can be represented by a function up to 10th order.

[0046] The intersection between the refraction surface and the optical axis is defined as the origin. The x-axis is set along the optical axis direction, the y-axis is set along an axis perpendicular to the optical axis in the main scanning section, and the z-axis is set along an axis perpendicular to the optical axis in the sub scanning section.

[0047] At this time, the meridional direction corresponding to the main scanning direction is given by

$$X = \frac{Y^2/R}{1+(1-(1+K)(Y/R)^2)^{1/2}} + B_4Y^4 + B_6Y^6 + B_8Y^8 + B_{10}Y^{10}$$

(where R is the radius of curvature, and K, B_4, B_6, B_8, and B_{10} are aspherical coefficients.)

[0048] The sagittal direction corresponding to the sub scanning direction (direction including the optical axis and perpendicular to the main scanning direction) is given by

$$S = \frac{Z^2/r'}{1+(1-(Z/r')^2)^{1/2}}$$

for $r' = = r_0(1 + D_2Y^2 + D_4Y^4 + D_6Y^6 + D_8Y^8 + D_{10}Y^{10})$

(where r_0 is the sagittal radius of curvature on the optical axis, and D_2, D_4, D_6, D_8, and D_{10} are aspherical coefficients.)

- Diffraction surface ... diffraction surface whose main scanning direction is represented by a function up to 6th order and sub scanning direction is represented by a 2nd-order phase function which changes depending on the position of the main scanning direction, which is represented by

$$\phi = m\lambda = b_2Y^2 + b_4Y^4 + b_6Y^6$$
$$+ (d_0 + d_1Y + d_2Y^2 + d_3Y^3 + d_4Y^4)Z^2$$

(where ϕ is the phase function, m is the order of diffraction, λ is the wavelength used, Y is the height from the optical axis of the lens, b_2, b_4, b_6, d_0, d_1, d_2, d_3, and d_4 are phase coefficients, and +1st-order diffracted light is used in the first to sixth embodiments.)

[0049] In this embodiment, the power layout of the toric lens 61 made of a plastic (polyolefin material: available from Zeonex) and the composite optical element 62 can be appropriately set to compensate for both an imaging position variation caused by the wavelength fluctuation of the light source in the main scanning direction and a focus variation caused by the environmental fluctuation (particularly temperature elevation) of the device in the sub scanning direction.

[0050] More specifically, in the first embodiment, the chromatic aberration of magnification of the scanning optical system is compensated in the main scanning direction by the refraction element (refraction portion) 61 having a positive dispersion and the diffraction element (diffraction portion) 62 having a negative dispersion (chromatic compensation of magnification). Letting ϕLm be the power of the refraction element 61 in the main scanning direction, vL be the Abbe number of the material of the refraction element 61, ϕDm be the power of the diffraction element 62 in the main scanning

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direction, and vD be the Abbe number of the material of the diffraction element 62, the power layout desirably satisfies

$$\phi Lm/vL + \phi Dm/vD = 0$$

[0051] The Abbe number has a limited range of values. The Abbe number is $20 \leq vL \leq 70$ as the distribution range of a general plastic material or glass material for the refraction element 61, and $vD = -3.45$ for the diffraction element 62 regardless of its material. The power ratio of the refraction element 61 to the diffraction element 62 in the main scanning direction desirably satisfies a condition:

$$5.8 \leq \phi Lm/\phi Dm \leq 20 \quad (1)$$

[0052] Condition (1) is related to the power ratio of the refraction element 61 to the diffraction element 62 in the main scanning direction that constitute the scanning optical element 6. A power layout which does not satisfy condition (1) is undesirable because it becomes difficult to correct an imaging position variation in the main scanning direction on the surface 8 to be scanned that is caused by the wavelength variation of the semiconductor laser 1.

[0053] In the sub scanning direction, the refractive index variation of the optical element caused by the environmental fluctuation (particularly temperature elevation) of the device is compensated by the wavelength variation of the semiconductor laser 1 caused by the same environmental fluctuation, thereby canceling focus movement (temperature compensation). A refractive index variation dn/dt and wavelength variation $d\lambda/dt$ per unit temperature are set to

$$dn/dt = -1.0E\text{-}4/°C$$

$$d\lambda/dt = 0.255\ nm/°C$$

Considering the refractive index of the material of the refraction element 61, and the possible value of the Abbe number, the power layout is desirably set to

$$1.0 \leq \phi Ls/\phi Ds \leq 2.6 \quad (2)$$

where

ϕLs: power of the refraction element in the sub scanning direction
ϕDs: power of the diffraction element in the sub scanning direction

[0054] Condition (2) is related to the power ratio of the refraction element 61 to the diffraction element 62 in the sub scanning direction that constitute the scanning optical element 6. A power layout which does not satisfy condition (2) is undesirable because it becomes difficult to correct a focus variation in the sub scanning direction along with the environmental fluctuation of the scanning optical device.

[0055] Table 1 shows the optical layout in the first embodiment, aspherical coefficients of the toric lens 61, and aspherical coefficients and phase terms of the composite optical element 62.

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[Table 1]

Numerical Data of First Embodiment

Design Data											
Wavelength, Refractive Index			Surface Shape of Toric Lens 61				Surface Shape of Elongated Diffraction Element 62				
					First Surface	Second Surface			First Surface	Second Surface
Wavelength Used	λ (nm)	780		R	-8.37256E+01	-4.46398E+01	R	-3.27422E+02	∞	
Refractive Index of Toric Lens 61	ndt	1.5306		K	-8.85666E+00	-5.33951E-01	K	-8.52087E+01		
↑ Abbe Number	vdt	55.5		B4	9.81713E-07	1.65579E-06	B4	1.59236E-07		
Refractive Index of Elongated Diffraction Element 62	ndd	1.5306		B6	-5.17945E-11	3.79299E-10	B6	-1.10765E-11		
↑ Abbe Number	vdd	55.5		r	1.25787E+02	-2.33970E+01	B8	3.70722E-16		
Light Ray Angle				D2s		1.42600E-04	B10	-4.86087E-21		
Angle of Incidence on Polygon	θp	-70.0		D4s		5.10858E-08	Phase Function of Elongated Diffraction Element 62			
Polygon Maximum Exit Angle	θe	45.0		D6s		3.98672E-13		First Surface	Second Surface	
Layout				D2e		2.14316E-04	b2		-1.72316E-04	
Polygon Surface - Toric Lens	e1	30.0		D4e		-1.22319E-08	b4		1.61040E-09	
Toric Lens Central Thickness	d1	11.0		D6e		3.61202E-11	b6		-1.12978E-13	
Toric Lens - Elongated Diffraction Element	e2	75.0	Suffixes s indicate laser side Suffixes e indicate side opposite to laser Y-axis sign + indicates side opposite to laser				d0		-5.10910E-03	
Elongated Diffraction Element Central Thickness	d2	4.0					d1		1.35226E-06	
Elongated Diffraction Element - Surface to be Scanned	Sk	110.0					d2		6.65427E-08	
Polygon Axis - Surface to be Scanned	L	230.0					d3		-6.20669E-11	
Effective Scanning Width	W	297.0					d4		1.01220E-12	

[0056] Power ratios of the refraction element 61 to the diffraction element 62 in the first embodiment are

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Main Scanning Direction: $\phi Lm/\phi Dm = 14.7$
Sub Scanning Direction: $\phi Ls/\phi Ds = 2.5$

These power ratios meet conditions (1) and (2).

[0057] Fig. 4 is a graph showing an imaging position variation in the main scanning direction caused by the wavelength variation of the semiconductor laser 1 in the first embodiment. Fig. 4 shows a difference (5 nm) from the initial wavelength of the semiconductor laser 1.

[0058] Fig. 5 is a graph showing paraxial aberration (curvature of field in the main scanning direction and sub scanning direction) before and after an environmental fluctuation in the first embodiment. The solid line represents a characteristic (design value) before an environmental fluctuation, and the broken line represents a characteristic (effective value) when the temperature is elevated by 25°C.

[0059] Generally in an apparatus which forms a color image by recording pieces of image information of respective colors on a plurality of photosensitive drums by a plurality of scanning optical devices, an imaging position deviation in the main scanning direction caused by the wavelength fluctuation of a semiconductor laser must be suppressed to 50 μm or less, and focus deviations in the main scanning direction and sub scanning direction caused by the environmental fluctuation (temperature fluctuation) of the device must be suppressed to ±1.0 mm or less, in order that misregistration between colors and image density nonuniformity between colors may be visually inconspicuous.

[0060] From Fig. 4, an imaging position deviation caused by a wavelength difference of +5 nm is 41 μm in the first embodiment, and corresponds to a pixel (position) deviation suppressed within about one pixel in, e.g., a printer having a resolution of 600 dpi. The initial wavelength deviation of a semiconductor laser between a plurality of colors, or mode hopping in activation is permitted by about 5 nm. Note that the initial wavelength deviation of a semiconductor laser between a plurality of colors means the individual difference between the wavelengths of respective semiconductor lasers in an image forming apparatus (so-called 4-drum color printer) which scans a plurality of image carrier surfaces with beams from a plurality of scanning optical devices.

[0061] Similarly from Fig. 5, the focus movement amount in the sub scanning direction at a temperature elevated by 25°C is 0.2 mm, and is suppressed to a visually negligible level both in the sub scanning direction and main scanning direction.

[0062] The behavior in temperature elevation has mainly been described for an environmental fluctuation. The same effects can also be attained even in another environmental fluctuation such as temperature drop.

[0063] The first embodiment compensates for all these environmental fluctuations using a plastic optical element. This can simultaneously reduce the manufacturing cost by molding and shorten the optical path by large-field-angle aberration correction using an aspherical surface.

[0064] As described above, the first embodiment uses the plastic toric lens 61 and composite optical element 62 as the scanning optical element 6 of the scanning optical device, and records images on a plurality of photosensitive drums by a plurality of scanning optical devices. A color image forming apparatus in which misregistration between colors caused by a wavelength fluctuation or environmental fluctuation, and density nonuniformity between colors are reduced can be implemented with a simple arrangement at low cost.

[Second Embodiment]

[0065] Fig. 6 is a sectional view of the main part of an optical system in the main scanning direction showing one of a plurality of scanning optical devices constituting a color image forming apparatus according to the second embodiment of the present invention, and a corresponding photosensitive drum. In Fig. 6, the same reference numerals as in Fig. 3 denote the same parts.

[0066] The second embodiment is different from the first embodiment in that a plastic toric lens as a refraction element is made of a material such as polycarbonate (PC) having a large dispersion, and that the power ratio of the refraction element to the diffraction element is optimized along with this change. The remaining arrangement and optical operation are almost the same as in the first embodiment, and provide the same effects.

[0067] In Fig. 6, a scanning optical element 16 as a third optical element (compensation means) having an f-θ characteristic has a refraction element 63 and diffraction element 64. The refraction element 63 is formed from a single plastic toric lens of a material such as polycarbonate (PC) having a large dispersion with different powers in the main scanning direction and sub scanning direction. Two lens surfaces 63a and 63b of the toric lens 63 in the main scanning direction are aspherical.

[0068] The diffraction element 64 is formed from an elongated composite optical element having different powers in the main scanning direction and sub scanning direction. An incident-side surface 64a of the composite optical element 64 is an aspherical surface having a predetermined power in only the main scanning direction (surface in the sub scanning direction is flat), whereas an exit-side surface 64b is a diffraction surface with a diffraction grating 82 added to a flat surface.

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[0069] Table 2 shows the optical layout in the second embodiment, aspherical coefficients of the toric lens 63, and aspherical coefficients and phase terms of the composite optical element 64.

[Table 2]

Numerical Data of Second Embodiment

Design Data										
Wavelength, Refractive Index				Surface Shape of Toric Lens 63			Surface Shape of Elongated Diffraction Element 64			
Wavelength Used	λ (nm)		780		First Surface	Second Surface			First Surface	Second Surface
Refractive Index of Toric Lens 63	ndt		1.5831	R	-8.19197E+01	-4.59294E+01	R		-3.36519E+02	∞
↑ Abbe Number	vdt		30.2	K	-9.39159E+00	-1.67046E+00	K		-5.60992E+01	
Refractive Index of Elongated Diffraction Element 64	ndd		1.5831	B4	8.03733E-07	2.46615E-07	B4		1.82411E-07	
↑ Abbe Number	vdd		30.2	B6	1.33079E-11	3.16577E-10	B6		-1.66927E-11	
Light Ray Angle				r	1.39988E+02	-2.53499E+01	B8		8.76950E-16	
Angle of Incidence on Polygon		θp	-70.0	D2s		1.45874E-04	B10		-2.12681E-20	
Polygon Maximum Exit Angle		θe	45.0	D4s		4.97782E-08	Phase Function of Elongated Diffraction Element 64			
				D6s		-1.80687E-12			First Surface	Second Surface
Layout				D2e		2.18066E-04	b2			-5.04969E-03
Polygon Surface - Toric Lens	e1		30.0	D4e		-1.51822E-08	b4			6.24030E-10
Toric Lens Central Thickness	d1		11.0	D6e		3.43111E-11	b6			-7.31370E-14
Toric Lens - Elongated Diffraction Element	e2		75.0	Suffices s indicate laser side Suffices e indicate side opposite to laser Y-axis sign + indicates side opposite to laser			d0			-5.13677E-03
Elongated Diffraction Element Central Thickness	d2		4.0				d1			1.36210E-06
Elongated Diffraction Element - Surface to be Scanned	Sk		110.0				d2			7.22724E-08
Polygon Axis - Surface to be Scanned	L		230.0				d3			-6.28966E-11
Effective Scanning Width	W		297.0				d4			8.09090E-13

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[0070] In the second embodiment, similar to the first embodiment, the power layout of the plastic toric lens 63 and composite optical element 64 can be appropriately set to compensate for both an imaging position variation caused by the wavelength variation of a semiconductor laser 1 in the main scanning direction and a focus variation caused by the environmental fluctuation (particularly temperature elevation) of the device in the sub scanning direction.

[0071] Power ratios of the refraction element 63 to the diffraction element 64 in the second embodiment are

Main Scanning Direction: $\phi Lm/\phi Dm = 13.0$
Sub Scanning Direction: $\phi Ls/\phi Ds = 2.5$

These power ratios meet conditions (1) and (2).

[0072] Fig. 7 is a graph showing an imaging position variation in the main scanning direction caused by the wavelength variation of the semiconductor laser 1 in the second embodiment. Fig. 7 shows a difference (5 nm) from the initial wavelength of the semiconductor laser 1.

[0073] Fig. 8 is a graph showing paraxial aberration (curvature of field in the main scanning direction and sub scanning direction) before and after an environmental fluctuation in the second embodiment. The solid line represents a characteristic (design value) before an environmental fluctuation, and the broken line represents a characteristic (effective value) when the temperature is elevated by 25°C.

[0074] From Fig. 7, an imaging position deviation caused by a wavelength difference of +5 nm is 40 μm (value when an image height with a landscape A3-size width of ±148.5 mm is measured) in the second embodiment, and corresponds to a pixel (position) deviation suppressed within about one pixel in, e.g., a printer having a resolution of 600 dpi. The initial wavelength deviation of the semiconductor laser 1 between a plurality of colors, or mode hopping in activation is permitted by about 5 nm.

[0075] Similarly from Fig. 8, the focus movement amount in the sub scanning direction at a temperature elevated by 25°C is 0.2 mm, and is suppressed to a visually negligible level both in the sub scanning direction and main scanning direction.

[0076] The behavior in temperature elevation has mainly been described for an environmental fluctuation. The same effects can also be attained even in another environmental fluctuation such as temperature drop.

[0077] The second embodiment compensates for all these environmental fluctuations using a plastic optical element. This can simultaneously reduce the manufacturing cost by molding and shorten the optical path by large-field-angle aberration correction using an aspherical surface.

[0078] As a characteristic feature unique to the second embodiment, the refraction element 63 is made of a material such as polycarbonate (PC) having a large dispersion. Therefore, the power of the diffraction element 64 can be relatively increased, which is effective in aberration correction and enables high-precision aberration correction.

[0079] As described above, the second embodiment uses the plastic toric lens 63 and composite optical element 64 as the scanning optical element 16 of the scanning optical device, and records images on a plurality of photosensitive drums by a plurality of scanning optical devices. A color image forming apparatus in which misregistration between colors caused by a wavelength fluctuation or environmental fluctuation, and density nonuniformity between colors are reduced can be implemented with a simple arrangement at low cost.

[Third Embodiment]

[0080] Fig. 9 is a sectional view of the main part of an optical system in the main scanning direction showing one of a plurality of scanning optical devices constituting a color image forming apparatus according to the third embodiment of the present invention, and a corresponding photosensitive drum. In Fig. 9, the same reference numerals as in Fig. 3 denote the same parts.

[0081] The third embodiment is different from the first embodiment in that a multi-semiconductor laser having a plurality of light-emitting portions (light-emitting points) is adopted as a light source means and that an imaging position deviation in the main scanning direction caused by the wavelength variation of the light source is compensated at high precision along with this change. The remaining arrangement and optical operation are almost the same as in the first embodiment, and provide the same effects.

[0082] In Fig. 9, a light source means 31 is formed from a multi-semiconductor laser (multi-beam laser source) having a plurality of light-emitting portions (two in the third embodiment), and emits a plurality of beams (only one beam is shown in Fig. 9) modulated independently.

[0083] A scanning optical element 26 as a third optical element (compensation means) having an f-θ characteristic has a refraction element 65 and diffraction element 66. The refraction element 65 is formed from a single plastic toric lens having different powers in the main scanning direction and sub scanning direction. Two lens surfaces 65a and 65b of the toric lens 65 in the main scanning direction are aspherical.

[0084] The diffraction element 66 is formed from an elongated composite optical element having different powers in

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the main scanning direction and sub scanning direction. An incident-side surface 66a of the composite optical element 66 is an aspherical surface having a predetermined power in only the main scanning direction (surface in the sub scanning direction is flat), whereas an exit-side surface 66b is a diffraction surface with a diffraction grating 83 added to a flat surface.

[0085] In the third embodiment, two beams emitted by the light source means 31 pass through the same path as in the first embodiment, and simultaneously scan a surface 8 in the sub scanning direction at a predetermined interval.

[0086] Table 3 shows the optical layout in the third embodiment, aspherical coefficients of the toric lens 65, and aspherical coefficients and phase terms of the composite optical element 66.

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[Table 3]

Numerical Data of Third Embodiment

Design Data											
Wavelength, Refractive Index				Surface Shape of Toric Lens 65			Surface Shape of Elongated Diffraction Element 66				
					First Surface	Second Surface			First Surface	Second Surface
Wavelength Used	λ (nm)	780	R		-8.68542E+01	-4.45747E+01	R		-2.71881E+02	∞
Refractive Index of Toric Lens 65	ndt	1.5306	K		-1.96906E+00	2.13828E-02	K		-4.62791E+01	
† Abbe Number	vdt	55.5	B4		1.83024E-06	2.11836E-06	B4		2.05587E-07	
Refractive Index of Elongated Diffraction Element 66	ndd	1.5306	B6		3.99262E-10	9.94640E-10	B6		-1.52060E-11	
† Abbe Number	vdd	55.5	B8		2.35548E-13	3.98293E-13	B8		5.90567E-16	
Light Ray Angle			B10		-4.32881E-17	2.55441E-16	B10		-1.28251E-20	
Angle of Incidence on Polygon	θp	-70.0	r		3.36183E+02	-2.14906E+01	Phase Function of Elongated Diffraction Element 66			
Polygon Maximum Exit Angle	θe	45.0	D2s			1.66335E-04			First Surface	Second Surface
			D4s			-1.28177E-07	b2			-1.50000E-04
Layout			D6s			1.39166E-10	b4			1.08606E-08
Polygon Surface - Toric Lens	e1	30.0	D2e			2.19201E-04	b6			-6.03566E-13
Toric Lens Central Thickness	d1	11.0	D4e			-1.59583E-07	d0			-5.03940E-03
Toric Lens - Elongated Diffraction Element	e2	71.9	D6e			1.52979E-10	d1			1.53717E-06
Elongated Diffraction Element Central Thickness	d2	4.0	Suffices s indicate laser side				d2			5.44808E-08
Elongated Diffraction Element - Surface to be Scanned	Sk	109.8	Suffices e indicate side opposite to laser				d3			-8.67550E-11
Polygon Axis - Surface to be Scanned	L	226.7	Y-axis sign + indicates side opposite to laser				d4			2.98778E-12
Effective Scanning Width	W	297.0								

[0087] In the third embodiment, similar to the first and second embodiments, the power layout of the plastic toric lens 65 and composite optical element 66 can be appropriately set to compensate for both an imaging position variation caused by the wavelength fluctuation of the multi-semiconductor laser 31 in the main scanning direction and a focus

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variation caused by the environmental fluctuation (particularly temperature elevation) of the device in the sub scanning direction. Moreover, the third embodiment can also compensate for a scanning interval variation (jitter) in the main scanning direction on the photosensitive drum surface 8 caused by the wavelength difference between a plurality of light-emitting portions.

[0088] Power ratios of the refraction element 65 to the diffraction element 66 in the third embodiment are

Main Scanning Direction: $\phi Lm/\phi Dm = 17.0$
Sub Scanning Direction: $\phi Ls/\phi Ds = 2.5$

These power ratios meet conditions (1) and (2).

[0089] Fig. 10 is a graph showing an imaging position variation in the main scanning direction caused by the wavelength variation of the multi-semiconductor laser 31 in the third embodiment. Fig. 10 shows a difference (5 nm) from the initial wavelength of the multi-semiconductor laser 31.

[0090] Fig. 11 is a graph showing paraxial aberration (curvature of field in the main scanning direction and sub scanning direction) before and after an environmental fluctuation in the third embodiment. The solid line represents a characteristic (design value) before an environmental fluctuation, and the broken line represents a characteristic (effective value) when the temperature is elevated by 25°C.

[0091] From Fig. 10, an imaging position deviation caused by a wavelength difference of +5 nm is 11 μm in the third embodiment, and corresponds to a pixel (position) deviation suppressed within about 1/4 pixel in, e.g., a printer having a resolution of 600 dpi. The initial wavelength deviation of the multi-semiconductor laser between a plurality of colors, the initial wavelength deviation between a plurality of light-emitting portions, or mode hopping in activation is permitted by about 5 nm.

[0092] Similarly from Fig. 11, the focus movement amount in the sub scanning direction at a temperature elevated by 25°C is 0.2 mm, and is suppressed to a visually negligible level both in the sub scanning direction and main scanning direction.

[0093] The behavior in temperature elevation has mainly been described for an environmental fluctuation. The same effects can also be attained even in another environmental fluctuation such as temperature drop.

[0094] The third embodiment compensates for all these environmental fluctuations using a plastic optical element. This can simultaneously reduce the manufacturing cost by molding and shorten the optical path by large-field-angle aberration correction using an aspherical surface.

[0095] As a characteristic feature unique to the third embodiment, the chromatic aberration of magnification (imaging position variation in the main scanning direction) caused by the wavelength fluctuation of the multi-semiconductor laser 31 is corrected at higher precision. Jitter caused by the wavelength difference between a plurality of light-emitting portions can also be reduced.

[0096] As described above, the third embodiment uses the plastic toric lens 65 and composite optical element 66 as the scanning optical element 26 of the scanning optical device, and records images on a plurality of photosensitive drums by a plurality of scanning optical devices. A color image forming apparatus in which jitter in the use of the multi-semiconductor laser is suppressed, and misregistration between colors caused by a wavelength fluctuation or environmental fluctuation, and density nonuniformity between colors are reduced can be implemented with a simple arrangement at low cost.

[0097] In each embodiment, a focus position variation in the sub scanning direction on a surface to be scanned that is caused by the environmental fluctuation of the device is compensated by the power variation of the refraction element and diffraction element and the wavelength variation of the light source means. As a matter of course, a focus position variation in the main scanning direction on a surface to be scanned that is caused by an environmental fluctuation is also compensated by the power variation of the refraction element and diffraction element and the wavelength variation of the light source means.

[Fourth Embodiment]

[0098] Fig. 12 is a sectional view (sectional view of main scanning) of the main part of an optical system showing one of a plurality of scanning optical devices constituting a color image forming apparatus in the main scanning direction according to the fourth embodiment of the present invention, and a corresponding photosensitive drum. In Fig. 12, the same reference numerals as in Fig. 3 denote the same parts.

[0099] The fourth embodiment is different from the first embodiment in that a multi-semiconductor laser (multi-beam laser source) having a plurality of light-emitting portions (light-emitting points) is adopted as a light source means, that the power ratio of the refraction element to diffraction element of a scanning optical element (third optical element) is appropriately set to compensate for an aberration variation along with an environmental fluctuation, and that an imaging position deviation caused by a wavelength variation not accompanied by any environmental fluctuation is set to a

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desired value or less. The remaining arrangement and optical action are almost the same as in the first embodiment, and provide the same effects.

[0100] In Fig. 12, a scanning optical element 36 as a third optical element having an f-θ characteristic has a refraction element 67 and diffraction element 68.

The refraction element 67 is formed from a single plastic toric lens having different powers in the main scanning direction and sub scanning direction. Two lens surfaces 67a and 67b of the toric lens 67 in the main scanning direction are aspherical.

[0101] The diffraction element 68 is formed from an elongated composite optical element having different powers in the main scanning direction and sub scanning direction. An incident-side surface 68a of the composite optical element 68 is an aspherical surface having a predetermined power in only the main scanning direction (surface in the sub scanning direction is flat), whereas an exit-side surface 68b is a diffraction surface with a diffraction grating 84 added to a flat surface.

[0102] In the fourth embodiment, the power layout of the plastic toric lens 67 and composite optical element 68 is appropriately set. In the main scanning direction, an imaging position deviation caused by a wavelength variation along with an environmental fluctuation, and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of an effective image region (effective scanning region). In the sub scanning direction, a focus variation caused by an environmental fluctuation is compensated.

[0103] Note that the environmental fluctuation means the temperature variation of the scanning optical device determined by self-temperature elevation in the scanning optical device, heat generation from another building component (fixing unit or the like) in the image forming apparatus, or an atmospheric variation at the installation location of the image forming apparatus.

[0104] In the fourth embodiment, the chromatic aberration of magnification of the entire scanning optical element 36 is compensated by excessive correction in the main scanning direction by the refraction element 67 having a positive dispersion and the diffraction element 68 having a negative dispersion. The reason of slightly excessively correcting the chromatic aberration of magnification is to change a wavelength variation along with the above-mentioned environmental fluctuation and an imaging position variation in the main scanning direction caused by a refractive index variation to directions in which these variations cancel each other. This increases the refracting power in the scanning optical system, and enhances the aberration correction effect by the diffraction element.

[0105] Letting ϕLm be the power of the refraction element 67 in the main scanning direction, vL be the Abbe number of the material of the refraction element 68, ϕDm be the power of the diffraction element 68 in the main scanning direction, and vD be the Abbe number of the material of the diffraction element 68, the power layout desirably satisfies

$$\phi Lm/vL + \phi Dm/vD \leq 0$$

[0106] The Abbe number has a limited range of values. The Abbe number is $20 \leq vL \leq 70$ as the distribution range of a general plastic material or glass material for the refraction element 67, and $vD = -3.45$ for the diffraction element 68 regardless of its material. The power ratio of the refraction element 67 to the diffraction element 68 in the main scanning direction desirably satisfies a condition:

$$vL/(2 \times 3.45) \leq \phi Lm/\phi Dm \leq vL/3.45$$

$$\therefore\ vL/6.90 \leq \phi Lm/\phi Dm \leq vL/3.45 \qquad (3)$$

[0107] If, however, the chromatic aberration of magnification is corrected too excessively, the imaging position in the main scanning direction varies due to a variation such as the initial wavelength deviation of the multi-semiconductor laser not accompanied by any environmental fluctuation, a discrete wavelength variation by mode hopping, or the wavelength deviation between a plurality of light sources of the multi-semiconductor laser. In particular, a wavelength variation by mode hopping of the multi-semiconductor laser is a discrete variation with high visibility. For this reason, an imaging position variation in the main scanning direction per unit mode hopping must be set to 3 μm or less at the two ends of the effective image region.

[0108] As will be described later, the fourth embodiment solves this problem by setting an imaging position variation in the main scanning direction per unit mode hopping of the multi-semiconductor laser to 3 μm or less at the two ends of the effective image region.

[0109] The mode hopping means a shift of an optical output from a laser during single-mode oscillation from a given longitudinal mode to another longitudinal mode. "Per unit mode hopping" means "per wavelength variation" caused by

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a change to an adjacent mode.

[0110] In the sub scanning direction, similar to the first embodiment, the refractive index variation of the scanning optical element caused by the environmental fluctuation (particularly temperature elevation) of the scanning optical device is compensated by the wavelength variation of the multi-semiconductor laser caused by a similar environmental fluctuation, thereby canceling focus movement (temperature compensation). A refractive index variation dn/dt and wavelength variation $d\lambda/dt$ per unit temperature are set to

$$dn/dt = -1.0E\text{-}4/°C$$

$$d\lambda/dt = 0.255\ nm/°C$$

Considering the refractive index of the material of the refraction element 67, and the possible value of the Abbe number, the power layout is desirably set to

$$1.0 \leq \phi Ls/\phi Ds \leq 2.6 \qquad (2)$$

where

ϕLs: power of the refraction element in the sub scanning direction
ϕDs: power of the diffraction element in the sub scanning direction

[0111] Table 4 shows the optical layout in the fourth embodiment, aspherical coefficients of the toric lens 67, and aspherical coefficients and phase terms of the composite optical element 68.

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[Table 4]

Numerical Data of Fourth Embodiment

Design Data									
Wavelength, Refractive Index			Surface Shape of Toric Lens 67			Surface Shape of Elongated Diffraction Element 68			
Wavelength Used	λ (nm)	780		First Surface	Second Surface			First Surface	Second Surface
Refractive Index of Toric Lens 67	ndt	1.5306	R	-8.37256E+01	-4.46398E+01	R		-3.27422E+02	∞
† Abbe Number	vdt	55.5	K	-8.85666E+00	-5.33951E-01	K		-8.52087E+01	
Refractive Index of Elongated Diffraction Element 68	ndd	1.5306	B4	9.81713E-07	1.65579E-06	B4		1.59236E-07	
† Abbe Number	vdd	55.5	B6	-5.17945E-11	3.79299E-10	B6		-1.10765E-11	
Light Ray Angle			r	1.25787E+02	-2.33970E+01	D8		3.70722E-16	
Angle of Incidence on Polygon	θp	-70.0	D2s		1.42600E-04	B10		-4.86087E-21	
Polygon Maximum Exit Angle	θe	45.0	D4s		5.10858E-08	Phase Function of Elongated Diffraction Element 68			
			D6s		3.98672E-13			First Surface	Second Surface
Layout			D2e		2.14316E-04	b2			-1.72316E-04
Polygon Surface - Toric Lens	e1	30.0	D4e		-1.22319E-08	b4			1.61040E-09
Toric Lens Central Thickness	d1	11.0	D6e		3.61202E-11	b6			-1.12978E-13
Toric Lens - Elongated Diffraction Element	e2	75.0	Suffices s indicate laser side Suffices e indicate side opposite to laser Y-axis sign + indicates side opposite to laser			d0			-5.10910E-03
Elongated Diffraction Element Central Thickness	d2	4.0				d1			1.35226E-06
Elongated Diffraction Element - Surface to be Scanned	Sk	110.0				d2			6.65427E-08
Polygon Axis - Surface to be Scanned	L	230.0				d3			-6.20669E-11
Effective Scanning Width	W	297.0				d4			1.01220E-12

[0112] Power ratios of the refraction element 67 to the diffraction element 68 in the fourth embodiment are

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Main Scanning Direction: $\phi Lm/\phi Dm = 14.7$
Sub Scanning Direction: $\phi Ls/\phi Ds = 2.5$

These power ratios meet excessive correction of the chromatic aberration of magnification and temperature compensation, i.e., conditions (3) and (2).

[0113] Fig. 13 is a graph showing an imaging position deviation at the end of the effective image region (most off-axis beam) when the scanning optical device in the fourth embodiment is elevated from room temperature (design temperature). The dotted line represents a component generated upon a decrease in the refractive index of the material of the scanning optical element along with temperature elevation. The chain line represents a component generated upon the wavelength variation of the multi-semiconductor laser along with temperature elevation. The solid line represents an imaging position deviation caused by temperature elevation as the total of these components, both of which are deviation amounts from the design temperature. At a temperature elevated by 25°C, the wavelength of the light source increases by $d\lambda = 6.375$ nm from the reference wavelength, and the refractive index of the scanning optical element decreases by $dn = 0.0025$.

[0114] From Fig. 13, excessive correction of the chromatic aberration of magnification changes the wavelength variation and refractive index variation of an imaging position deviation in opposite directions, i.e., directions in which the imaging position deviation by temperature elevation is canceled.

[0115] Fig. 14 is a graph showing an imaging position deviation as a function of a wavelength variation not accompanied by temperature elevation at the end of the effective image region (most off-axis beam). Fig. 14 shows a deviation amount from the reference wavelength.

[0116] From Fig. 14, an imaging position deviation in the main scanning direction per unit mode hopping (0.3 nm in the multi-semiconductor laser of the fourth embodiment) is about 1.3 μm which is substantially negligible with respect to a discrete wavelength variation.

[0117] Fig. 15 is a graph showing paraxial aberration (focus position in the main scanning direction and sub scanning direction) before and after an environmental fluctuation in the fourth embodiment. The solid line represents a characteristic (design value) before an environmental fluctuation, and the broken line represents a characteristic (effective value) when the temperature of the scanning optical device is elevated by 25°C.

[0118] Generally in an apparatus which forms a color image by recording pieces of image information of respective colors on a plurality of photosensitive drums by a plurality of scanning optical devices, focus deviations in the main scanning direction and sub scanning direction caused by an environmental fluctuation must be suppressed to ±1.0 mm or less in order that misregistration between colors and image density nonuniformity between colors may be visually inconspicuous.

[0119] From Fig. 15, the focus movement amount in the sub scanning direction at a temperature elevated by 25°C is 0.2 mm in the fourth embodiment, and is suppressed to a visually negligible level both in the sub scanning direction and main scanning direction.

[0120] The behavior in temperature elevation has mainly been described for an environmental fluctuation. The same effects can also be attained even in another environmental fluctuation such as temperature drop.

[0121] The fourth embodiment compensates for all these environmental fluctuations using a plastic optical element. This can simultaneously reduce the manufacturing cost by molding and shorten the optical path by large-field-angle aberration correction using an aspherical surface.

[0122] As described above, the fourth embodiment appropriately sets the powers of the refraction element and diffraction element as the scanning optical element of the scanning optical device such that an imaging position deviation in the main scanning direction caused by a wavelength variation along with an environmental fluctuation, and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of the effective image region, thereby reducing an imaging position deviation caused by an environmental fluctuation. At the same time, an imaging position deviation caused by a wavelength variation not accompanied by any environmental fluctuation is also set to a desired value or less, thereby implementing a scanning optical device resistant to a wavelength fluctuation or environmental fluctuation.

[0123] As described above, the fourth embodiment uses a plurality of scanning optical devices to record images on a plurality of photosensitive drum surfaces. A color image forming apparatus in which misregistration between colors caused by a wavelength fluctuation or environmental fluctuation, and density nonuniformity between colors are reduced can be implemented with a simple arrangement at low cost.

[0124] Note that the fourth embodiment has exemplified the use of a multi-beam laser source for a tandem type color image forming apparatus whose precision requirement is the highest. However, this embodiment is effective regardless of the type of scanning optical device such as a color/monochrome device or a single-beam laser source/multi-beam laser source.

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[Fifth Embodiment]

[0125] Fig. 16 is a sectional view (sectional view of main scanning) of the main part of an optical system showing one of a plurality of scanning optical devices constituting a'color image forming apparatus in the main scanning direction according to the fifth embodiment of the present invention, and a corresponding photosensitive drum. In Fig. 16, the same reference numerals as in Fig. 12 denote the same parts.

[0126] The fifth embodiment is different from the fourth embodiment in that a semiconductor laser (single-beam laser source) having a single light-emitting portion is used as a light source means, and that the power ratio of the refraction element to diffraction element of the scanning optical element is optimized. The remaining arrangement and optical action are almost the same as in the fourth embodiment, and provide the same effects.

[0127] In Fig. 16, a scanning optical element 46 as a third optical element having an f-θ characteristic has a refraction element 69 and diffraction element 70. The refraction element 69 is formed from a single plastic toric lens having different powers in the main scanning direction and sub scanning direction. Two lens surfaces 69a and 69b of the toric lens 69 in the main scanning direction are aspherical.

[0128] The diffraction element 70 is formed from an elongated composite optical element having different powers in the main scanning direction and sub scanning direction. An incident-side surface 70a of the composite optical element 70 is an aspherical surface having a predetermined power in only the main scanning direction (surface in the sub scanning direction is flat), whereas an exit-side surface 70b is a diffraction surface with a diffraction grating 85 added to a flat surface.

[0129] Table 5 shows the optical layout in the fifth embodiment, aspherical coefficients of the toric lens 69, and aspherical coefficients and phase terms of the composite optical element 70.

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[Table 5]

Numerical Data of Fifth Embodiment

Design Data												
Wavelength, Refractive Index				Surface Shape of Toric Lens 69				Surface Shape of Elongated Diffraction Element 70				
Wavelength Used	λ (nm)	780		First Surface		Second Surface				First Surface		Second Surface
Refractive Index of Toric Lens 69	ndt	1.5306	R	-8.53751E+01		-4.55667E+01		R		-3.43494E+02		∞
↑ Abbe Number	vdt	55.5	K	2.24374E-01		-8.11042E-01		K		-4.10368E+01		
Refractive Index of Elongated Diffraction Element 70	ndd	1.5306	B4	1.94226E-06		6.82494E-07		B4		2.14788E-07		
↑ Abbe Number	vdd	55.5	B6	8.04096E-10		5.53491E-10		B6		-1.99348E-11		
Light Ray Angle			B8	-6.69880E-13		4.54457E-13		B8		1.07627E-15		
Angle of Incidence on Polygon	θp	-70.0	B10	1.00167E-16		-3.02377E-16		B10		-2.82629E-20		
Polygon Maximum Exit Angle	θe	45.0	r	1.25791E+02		-2.35075E+01		Phase Function of Elongated Diffraction Element 70				
			D2s			1.42836E-04				First Surface		Second Surface
Layout			D4s			4.11761E-08		b2				-2.80000E-04
Polygon Surface - Toric Lens	e1	30.0	D6s			7.72220E-12		b4				1.06258E-08
Toric Lens Central Thickness	d1	11.0	D2e			2.17519E-04		b6				-1.41997E-12
Toric Lens - Elongated Diffraction Element	e2	75.0	D4e			-3.46459E-08		b8				1.14984E-16
Elongated Diffraction Element Central Thickness	d2	5.0	D6e			5.36631E-11		b10				-4.39247E-21
Elongated Diffraction Element - Surface to be Scanned	Sk	111.0	Suffices s indicate laser side Suffices e indicate side opposite to laser Y-axis sign + indicates side opposite to laser					d0				-5.11279E-03
Polygon Axis - Surface to be Scanned	L	232.0						d1				1.32455E-06
Effective Scanning Width	W	297.0						d2				6.53368E-08
								d3				-5.97665E-11
								d4				1.11649E-12

[0130] In the fifth embodiment, similar to the fourth embodiment, the power layout of the plastic toric lens 69 and

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composite optical element 70 is appropriately set. In the main scanning direction, an imaging position variation caused by a wavelength variation along with an environmental fluctuation, and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of the effective image region. In the sub scanning direction, a focus variation caused by an environmental fluctuation is compensated.

[0131] Power ratios of the refraction element 69 to the diffraction element 70 in the fifth embodiment are

Main Scanning Direction: $\phi Lm/\phi Dm = 8.8$
Sub Scanning Direction: $\phi Ls/\phi Ds = 2.5$

These power ratios meet excessive correction of the chromatic aberration of magnification and temperature compensation, i.e., conditions (3) and (2).

[0132] Fig. 17 is a graph showing an imaging position deviation at the end of the effective image region (most off-axis beam) when the scanning optical device in the fifth embodiment is elevated from room temperature (design temperature). The dotted line represents a component generated upon a decrease in the refractive index of the material of the scanning optical element along with temperature elevation. The chain line represents a component generated upon the wavelength variation of the semiconductor laser along with temperature elevation. The solid line represents an imaging position deviation caused by temperature elevation as the total of these components, both of which are deviation amounts from the design temperature. At a temperature elevated by 25°C, the wavelength of the light source increases by $d\lambda = 6.375$ nm from the reference wavelength, and the refractive index of the scanning optical element decreases by $dn = 0.0025$.

[0133] From Fig. 17, excessive correction of the chromatic aberration of magnification changes the wavelength variation and refractive index variation of an imaging position deviation in opposite directions, i.e., directions in which the imaging position deviation by temperature elevation is canceled. In particular, the fifth embodiment relatively increases the power of the diffraction element, thereby increasing an imaging position deviation caused by the wavelength variation of the semiconductor laser along with temperature elevation, and enhancing the correction effect together with a component generated upon a decrease in the refractive index of the material of the scanning optical element.

[0134] Fig. 18 is a graph showing an imaging position deviation as a function of a wavelength variation not accompanied by temperature elevation at the end of the effective image region (most off-axis beam). Fig. 18 shows a deviation amount from the reference wavelength.

[0135] From Fig. 18, an imaging position deviation in the main scanning direction per unit mode hopping (0.3 nm in the semiconductor laser of the fifth embodiment) is about 2.0 μm which is substantially negligible with respect to a discrete wavelength variation.

[0136] Fig. 19 is a graph showing paraxial aberration (focus position in the main scanning direction and sub scanning direction) before and after an environmental fluctuation in the fifth embodiment. The solid line represents a characteristic (design value) before an environmental fluctuation, and the broken line represents a characteristic (effective value) when the temperature of the scanning optical device is elevated by 25°C.

[0137] From Fig. 19, the focus movement amount in the sub scanning direction at a temperature elevated by 25°C is 0.2 mm in the fifth embodiment, and is suppressed to a visually negligible level both in the sub scanning direction and main scanning direction.

[0138] The behavior in temperature elevation has mainly been described for an environmental fluctuation. The same effects can also be attained even in another environmental fluctuation such as temperature drop.

[0139] As described above, the fifth embodiment appropriately sets the powers of the refraction element and diffraction element as the scanning optical element of the scanning optical device such that an imaging position deviation in the main scanning direction caused by a wavelength variation along with an environmental fluctuation, and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of the effective image region, thereby reducing an imaging position deviation caused by an environmental fluctuation. At the same time, an imaging position deviation caused by a wavelength variation not accompanied by any environmental fluctuation is also set to a desired value or less, thereby implementing a scanning optical device resistant to a wavelength variation or environmental variation. Especially in this embodiment, the power of the diffraction element is relatively increased to increase an imaging position deviation caused the wavelength variation of the semiconductor laser along with temperature elevation and to enhance the correction effect together with a component generated upon a decrease in the refractive index of the material of the scanning optical element. A scanning optical device more resistant to an environmental variation is implemented.

[0140] As described above, the fifth embodiment uses a plurality of scanning optical devices to record images on a plurality of photosensitive drum surfaces. A color image forming apparatus in which misregistration between colors caused by a wavelength fluctuation or environmental fluctuation, and density nonuniformity between colors are reduced can be implemented with a simple arrangement at low cost.

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[Sixth Embodiment]

[0141] Fig. 20 is a sectional view (sectional view of main scanning) of the main part of an optical system showing one of a plurality of scanning optical devices constituting a color image forming apparatus in the main scanning direction according to the sixth embodiment of the present invention, and a corresponding photosensitive drum. In Fig. 20, the same reference numerals as in Fig. 12 denote the same parts.

[0142] The sixth embodiment is different from the fifth embodiment in that a plastic toric lens as a refraction element is made of a material such as polycarbonate (PC) having a large dispersion, and that the power ratio of the refraction element to the diffraction element is optimized. The remaining arrangement and optical action are almost the same as in the fifth embodiment, and provide the same effects.

[0143] In Fig. 20, a scanning optical element 56 as a third optical element having an f-θ characteristic has a refraction element 71 and diffraction element 72. The refraction element 71 is formed from a single plastic toric lens of a material such as polycarbonate (PC) having a large dispersion with different powers in the main scanning direction and sub scanning direction. Two lens surfaces 61a and 71b of the toric lens 71 in the main scanning direction are aspherical.

[0144] The diffraction element 72 is formed from an elongated composite optical element having different powers in the main scanning direction and sub scanning direction. An incident-side surface 72a of the composite optical element 72 is an aspherical surface having a predetermined power in only the main scanning direction (surface in the sub scanning direction is flat), whereas an exit-side surface 72b is a diffraction surface with a diffraction grating 86 added to a flat surface.

[0145] Table 6 shows the optical layout in the sixth embodiment, aspherical coefficients of the toric lens 71, and aspherical coefficients and phase terms of the composite optical element 72.

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[Table 6]

Numerical Data of Sixth Embodiment

Design Data												
Wavelength, Refractive Index				Surface Shape of Toric Lens 71				Surface Shape of Elongated Diffraction Element 72				
Wavelength Used	λ (nm)		780		First Surface	Second Surface			First Surface	Second Surface
Refractive Index of Toric Lens 71	ndt	1.5831		R	-8.32474E+01	-4.66932E+01		R	-3.36204E+02	8
† Abbe Number	vdt	30.2		K	-1.49053E+00	-1.38959E+00		K	-7.11436E+01	
Refractive Index of Elongated Diffraction Element 72	ndd	1.5831		B4	1.00553E-06	-1.75207E-07		B4	1.91392E-07	
† Abbe Number	vdd	30.2		B6	1.45168E-09	1.59223E-10		B6	-1.92184E-11	
Light Ray Angle				B8	-1.11489E-12	1.05725E-12		B8	1.14343E-15	
Angle of Incidence on Polygon	θp	-70.0		B10	9.69064E-17	-6.51123E-16		D10	-3.16357E-20	
Polygon Maximum Exit Angle	θe	45.0		r	-1.44495E+02	-2.53648E+01	Phase Function of Elongated Diffraction Element 72			
				D2s		1.38486E-04			First Surface	Second Surface
Layout				D4s		5.58624E-08		b2		-3.00000E-04
Polygon Surface - Toric Lens	e1	30.0		D6s		-1.87841E-11		b4		3.89698E-08
Toric Lens Central Thickness	d1	11.0		D2e		2.13552E-04		b6		-6.36212E-12
Toric Lens - Elongated Diffraction Element	e2	75.0		D4e		-2.26154E-08		b8		4.84188E-16
Elongated Diffraction Element Central Thickness	d2	5.0		D6e		2.79865E-11		b10		-1.43626E-20
Elongated Diffraction Element - Surface to be Scanned	Sk	111.0		Suffices s indicate laser side Suffices e indicate side opposite to laser Y-axis sign + indicates side opposite to laser				d0		-5.13463E-03
Polygon Axis - Surface to be Scanned	L	232.0						d1		1.33067E-06
Effective Scanning Width	W	297.0						d2		6.96282E-08
								d3		-5.92953E-11
								d4		6.55739E-13

[0146] In the sixth embodiment, similar to the fifth embodiment, the power layout of the plastic toric lens 71 and composite optical element 72 is appropriately set. In the main scanning direction, an imaging position variation caused

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by a wavelength variation along with an environmental fluctuation, and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of the effective image region. In the sub scanning direction, a focus variation caused by an environmental variation is compensated.

[0147] Power ratios of the refraction element 71 to the diffraction element 72 in the sixth embodiment are

Main Scanning Direction: $\phi Lm/\phi Dm = 8.2$
Sub Scanning Direction: $\phi Ls/\phi Ds = 2.5$

These power ratios meet excessive correction of the chromatic aberration of magnification and temperature compensation, i.e., conditions (3) and (2).

[0148] As a characteristic feature unique to the sixth embodiment, the refraction element is made of a material such as PC having a large dispersion. Hence, the power of the diffraction element can be relatively increased, which is effective in aberration correction and enables high-precision aberration correction.

[0149] Fig. 21 is a graph showing an imaging position deviation at the end of the effective image region (most off-axis beam) when the scanning optical device in the sixth embodiment is elevated from room temperature (design temperature). The dotted line represents a component generated upon a decrease in the refractive index of the material of the scanning optical element along with temperature elevation. The chain line represents a component generated upon the wavelength variation of the semiconductor laser along with temperature elevation. The solid line represents an imaging position deviation caused by temperature elevation as the total of these components, both of which are deviation amounts from the design temperature. At a temperature elevated by 25°C, the wavelength of the light source increases by $d\lambda = 6.375$ nm from the reference wavelength, and the refractive index of the scanning optical element decreases by $dn = 0.0025$.

[0150] From Fig. 21, excessive correction of the chromatic aberration of magnification changes the wavelength variation and refractive index variation of an imaging position deviation in opposite directions, i.e., directions in which the imaging position deviation by temperature elevation is canceled.

[0151] Fig. 22 is a graph showing an imaging position deviation as a function of a wavelength variation not accompanied by temperature elevation at the end of the effective image region (most off-axis beam). Fig. 22 shows a deviation amount from the reference wavelength.

[0152] From Fig. 22, an imaging position deviation in the main scanning direction per unit mode hopping (0.3 nm in the semiconductor laser of the sixth embodiment) is about 1.2 μm which is substantially negligible with respect to a discrete wavelength variation.

[0153] Fig. 23 is a graph showing paraxial aberration (focus position in the main scanning direction and sub scanning direction) before and after an environmental fluctuation in the sixth embodiment. The solid line represents a characteristic (design value) before an environmental fluctuation, and the broken line represents a characteristic (effective value) when the temperature of the scanning optical device is elevated by 25°C.

[0154] From Fig. 23, the focus movement amount in the sub scanning direction at a temperature elevated by 25°C is 0.2 mm in the sixth embodiment, and is suppressed to a visually negligible level both in the sub scanning direction and main scanning direction.

[0155] The behavior in temperature elevation has mainly been described for an environmental fluctuation. The same effects can also be attained even in another environmental fluctuation such as temperature drop.

[0156] As described above, the sixth embodiment appropriately sets the powers of the refraction element and diffraction element as the scanning optical element of the scanning optical device such that an imaging position deviation in the main scanning direction caused by a wavelength variation along with an environmental fluctuation, and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of the effective image region, thereby reducing an imaging position deviation caused by an environmental variation. At the same time, an imaging position deviation caused by a wavelength variation not accompanied by any environmental fluctuation is also set to a desired value or less, thereby implementing a scanning optical device resistant to a wavelength fluctuation or environmental fluctuation. In particular, this embodiment can use PC with a large dispersion to increase the power of the diffraction element, thus implementing a scanning optical device which corrects aberration at high precision.

[0157] As described above, the sixth embodiment uses a plurality of scanning optical devices to record images on a plurality of photosensitive drum surfaces. A color image forming apparatus in which misregistration between colors caused by a wavelength fluctuation or environmental fluctuation, and density nonuniformity between colors are reduced can be implemented with a simple arrangement at low cost.

[0158] The image forming apparatus in Fig. 1 that is applied to the present invention will be explained in more detail with r ference to Fig. 26.

[0159] Fig. 26 is a schematic view showing the main part of an image forming apparatus. This embodiment concerns

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a tandem type color image forming apparatus in which four scanning optical devices are aligned to record pieces of image information on photosensitive drum surfaces serving as image carriers in parallel with each other. In Fig. 26, a color image forming apparatus 160 comprises scanning optical devices 111, 112, 113, and 114 having any one of the arrangements described in the first to sixth embodiments, photosensitive drums 121, 122, 123, and 124 serving as image carriers, developing units 131, 132, 133, and 134, and a convey belt 151.

[0160] In Fig. 26, the color image forming apparatus 160 receives R (Red), G (Green), and B (Blue) color signals from an external device 152 such as a personal computer. These color signals are converted into C (Cyan), M (Magenta), Y (Yellow), and B (Black) image data (dot data) by a printer controller 153 in the apparatus. These image data are respectively input to the scanning optical devices 111, 112, 113, and 114. The scanning optical devices emit beams 141, 142, 143, and 144 modulated in accordance with these image data. The beams scan the photosensitive surfaces of the photosensitive drums 121, 122, 123, and 124 in the main scanning direction.

[0161] In the color image forming apparatus of this embodiment, the four scanning optical devices (111, 112, 113, and 114) are aligned, respectively correspond to C (Cyan), M (Magenta), Y (Yellow), and B (Black) colors, and record image signals (image information) on the surfaces of the photosensitive drums 121, 122, 123, and 124 in parallel with each other, thereby printing a color image at a high speed.

[0162] In the color image forming apparatus of this embodiment, the four scanning optical devices 111, 112, 113, and 114 use beams based on their image data to form latent images of the respective colors on the surfaces of the corresponding photosensitive drums 121, 122, 123, and 124. After that, the latent images are multiple-transferred to a recording medium to form one full-color image.

[0163] As the external device 152, e.g., a color image reading device having a CCD sensor may be used. In this case, the color image reading device and the color image forming apparatus 160 constitute a color digital copying machine.

[0164] As has been described above, the present invention can achieve a compact scanning optical device and color image forming apparatus suitable for high-resolution printing in which an imaging position variation caused by the wavelength variation of a light source means, an aberration variation upon an environmental variation (temperature variation), and the like in each scanning optical device are compensated by a compensation means (third optical element) in a color image forming apparatus having a plurality of scanning optical devices, thereby suppressing an imaging position deviation in especially the main scanning direction, and reducing a color deviation and image density nonuniformity at low cost with a simple arrangement.

[0165] As has been described above, the present invention can achieve a scanning optical device and color image forming apparatus in which a refraction element and diffraction element are used as the scanning optical element of a scanning optical device, the powers of the refraction element and diffraction element are set such that an imaging position deviation in the main scanning direction caused by a wavelength variation along with the environmental fluctuation of the scanning optical device and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of an effective image region (effective scanning region), thereby reducing an imaging position deviation caused by an environmental fluctuation, and at the same time an imaging position deviation caused by a wavelength variation not accompanied by any environmental fluctuation is also set to a desired value or less, thereby implementing a scanning optical device resistant to a wavelength fluctuation or environmental fluctuation, and

in which images are recorded on a plurality of image carriers (photosensitive drums) using a plurality of scanning optical devices, thereby implementing with a simple arrangement at low cost a color image forming apparatus which is almost free from misregistration between colors caused by a wavelength fluctuation or environmental fluctuation and almost free from density nonuniformity between colors.

Claims

1. A scanning optical device including light source means, and an optical element having a refraction element and a diffraction element,

   characterized in that powers of said refraction element and said diffraction element are set such that an imaging position deviation in a main scanning direction on a surface to be scanned that is caused by a wavelength variation of a beam emitted by said light source means along with an environmental fluctuation of said scanning optical device, and an imaging position deviation in the main scanning direction on the surface to be scanned that is caused by a refractive index variation of a material of said optical element along with an environmental fluctuation are set to be in opposite directions at two ends of an effective scanning region.

2. A device according to claim 1, characterized in that said optical element includes an element which forms the beam emitted by said light source means into an image on the surface to be scanned, and letting ϕLm and ϕDm be

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powers of said refraction element and diffraction element constituting said optical element in the main scanning direction, and vL be an Abbe number of a material of said refraction element, the powers satisfy a condition:

$$vL/6.90 \leq \phi Lm/\phi Dm \leq vL/3.45$$

3. A device according to claim 2, characterized in that an imaging position variation per unit mode hopping of said light source means is not more than 3 μm at the two ends of the effective scanning region.

4. A device according to claim 1 or 2, characterized in that a focus position deviation in a sub scanning direction on the surface to be scanned that is caused by the wavelength variation of the beam emitted by said light source means along with the environmental fluctuation, and a focus position deviation in the sub scanning direction on the surface to be scanned that is caused by the refractive index variation of the material of said optical element along with the environmental fluctuation are substantially compensated within the effective scanning region.

5. A device according to any one of claims 1 to 3, characterized in that the environmental fluctuation includes an atmospheric variation of said scanning optical device and a temperature variation caused by self-temperature elevation.

6. A device according to any one of claims 1 to 4, characterized in that said refraction element includes a toric lens, and said diffraction element includes a composite optical element obtained by integrating a refraction surface and a diffraction surface.

7. A device according to any one of claims 1 to 5, characterized in that said refraction element and diffraction element constituting said optical element are formed from a plastic material.

8. A device according to any one of claims 1 to 6, characterized in that said light source means includes a multi-beam laser source having a plurality of light-emitting portions.

9. A device according to any one of claims 1 to 8, characterized in that letting ϕLs and ϕDs be powers of said refraction element and diffraction element constituting said optical element in a sub scanning direction, the powers satisfy a condition:

$$1.0 \leq \phi Ls/\phi Ds \leq 2.6$$

10. A device according to any one of claims 1 to 9, characterized in that the powers of said refraction element and said diffraction element are set to compensate for an imaging position variation in the main scanning direction on the surface to be scanned that is caused by a wavelength fluctuation of the beam emitted by said light source means.

11. An image forming apparatus characterized in that said image forming apparatus comprises a plurality of pairs of scanning optical devices defined in any one of claims 1 to 10 and corresponding image carriers, guides beams emitted by said scanning optical devices to corresponding image carriers, scans surfaces of said image carriers to form images of different colors on the surfaces of said image carriers, and forms a color image by the images formed on the surfaces of said image carriers.

12. An image forming apparatus characterized by comprising a scanning optical device defined in any one of claims 1 to 10, and a printer controller for converting code data input from an external device into an image signal and inputting the converted image signal to said scanning optical device.

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FIG. 1

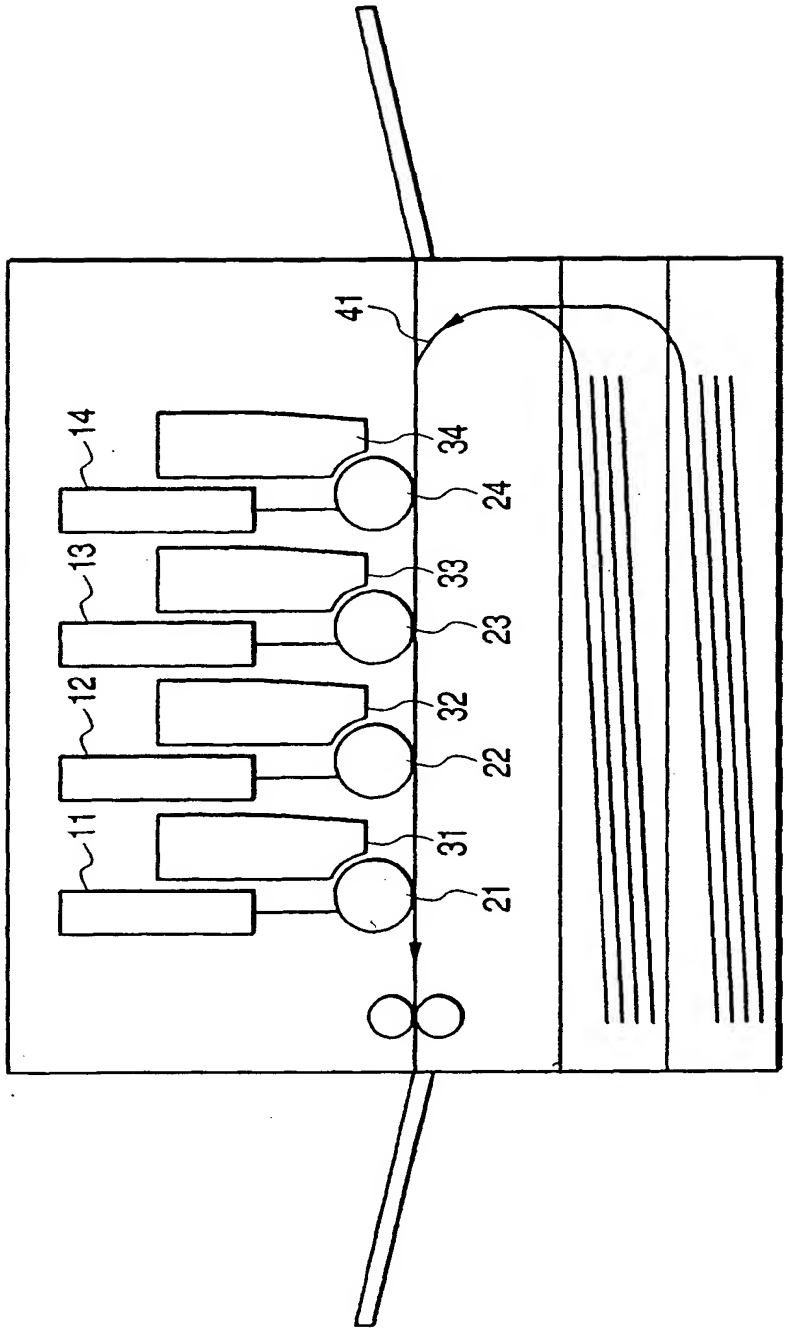

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FIG. 2

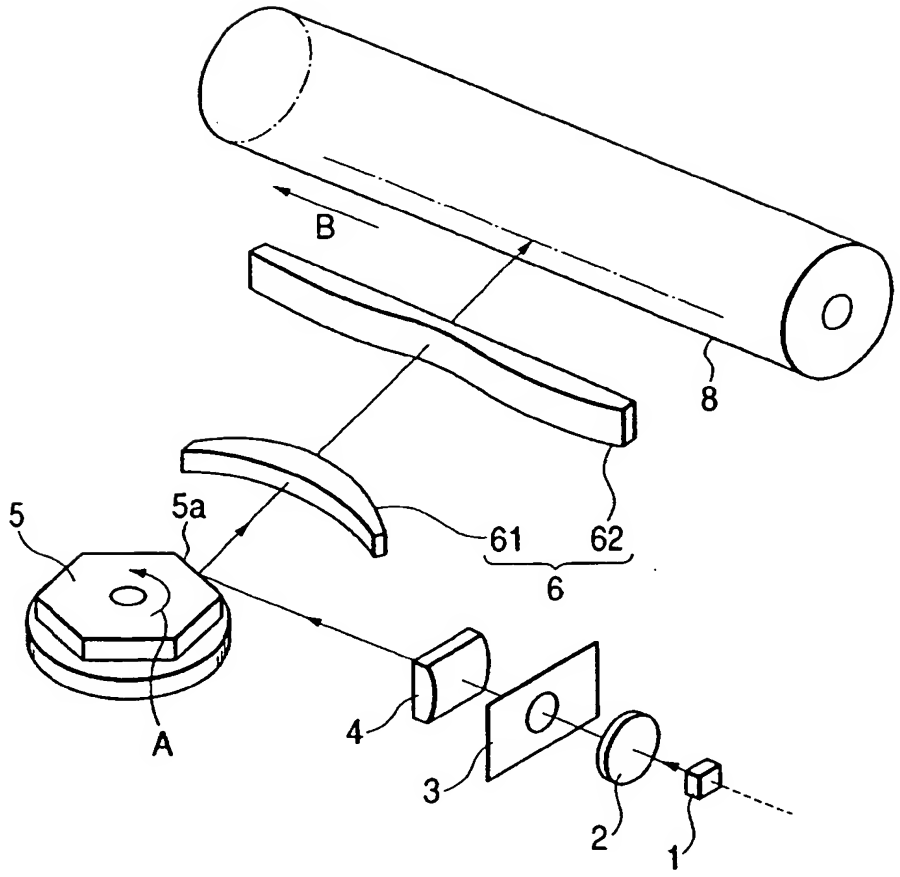

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FIG. 3

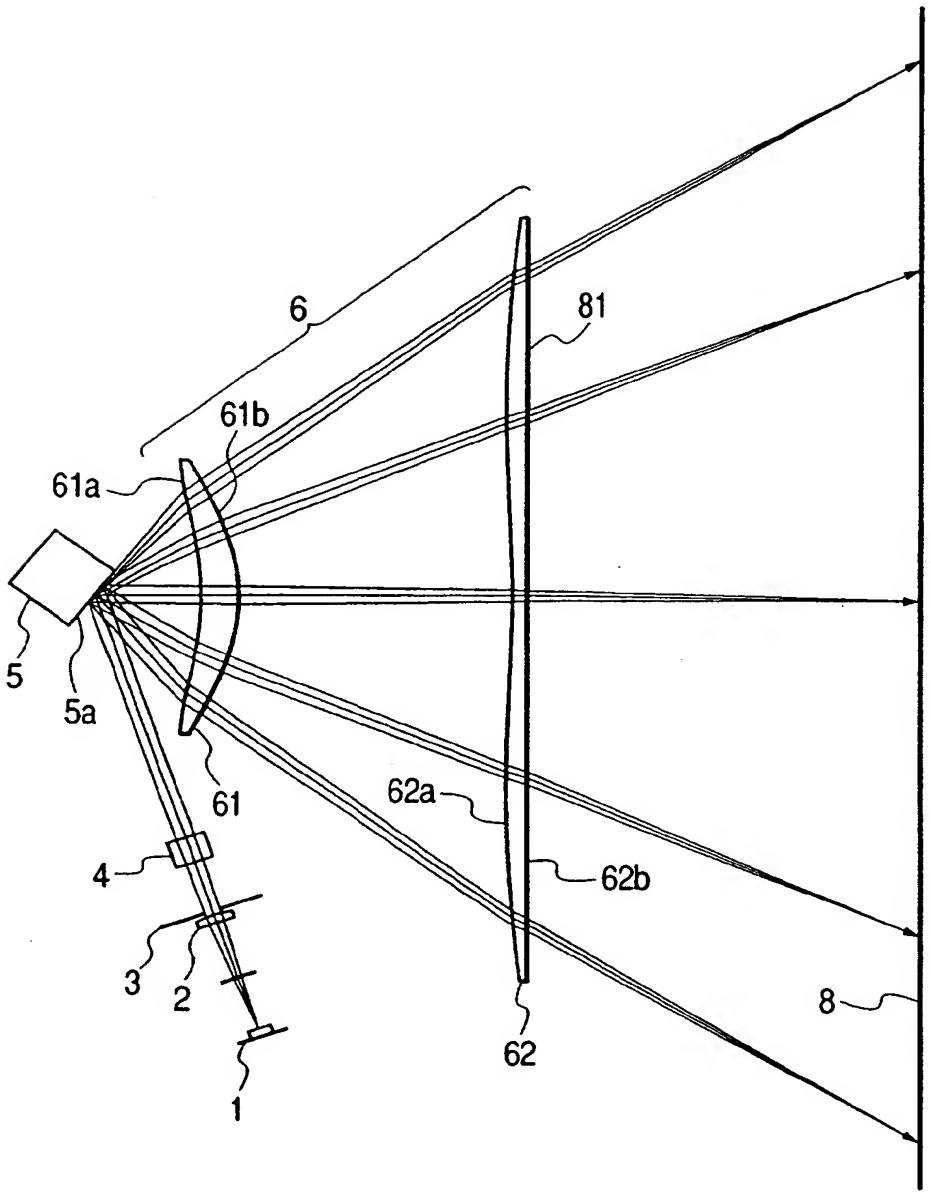

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FIG. 4

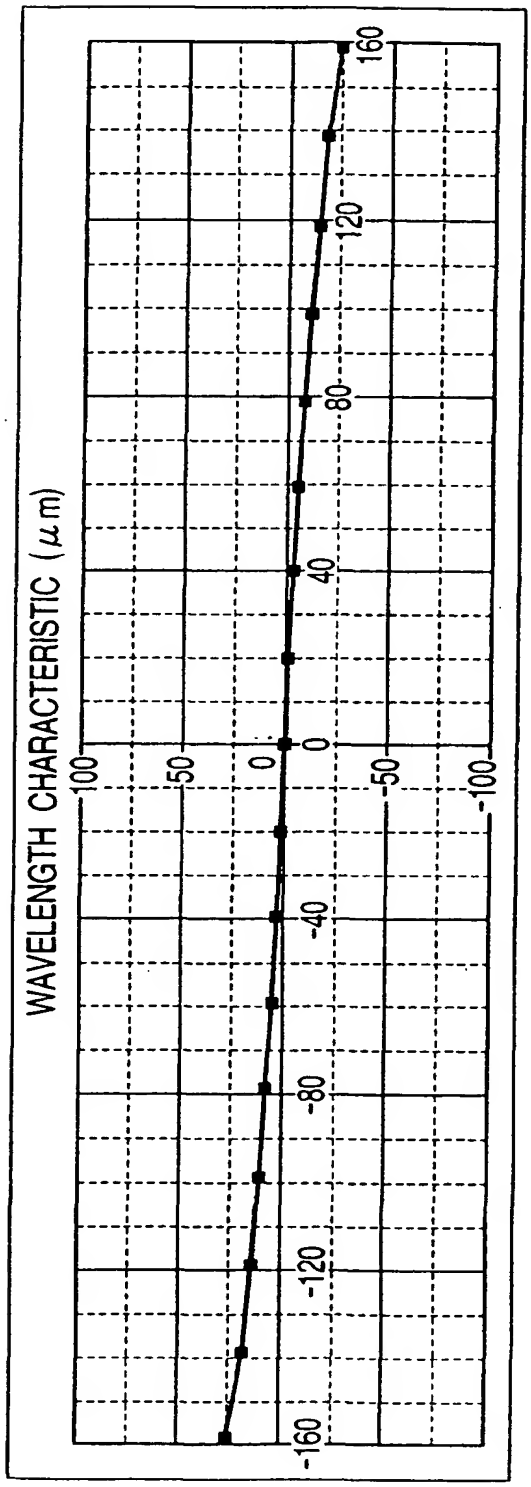

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FIG. 5

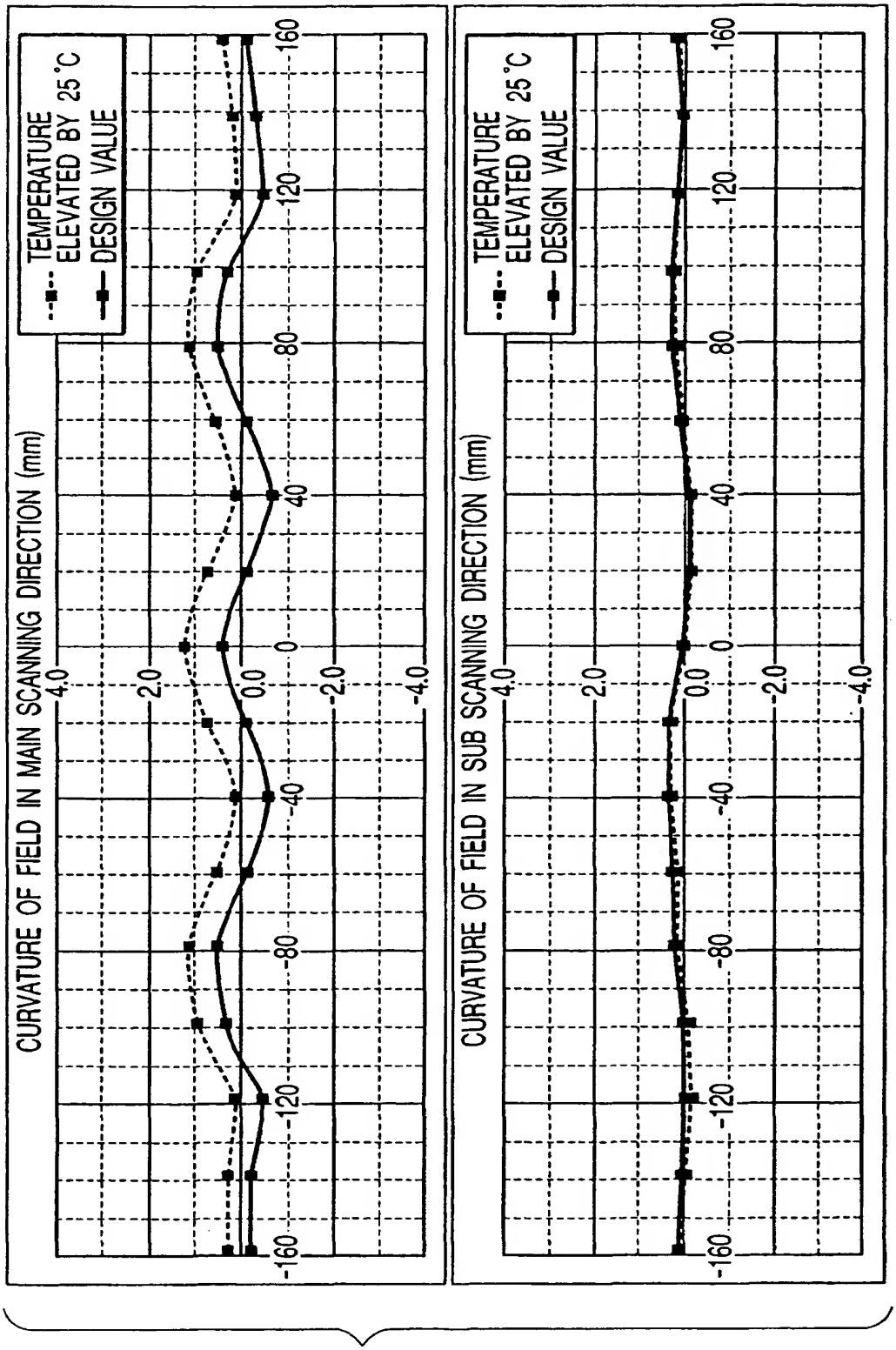

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FIG. 6

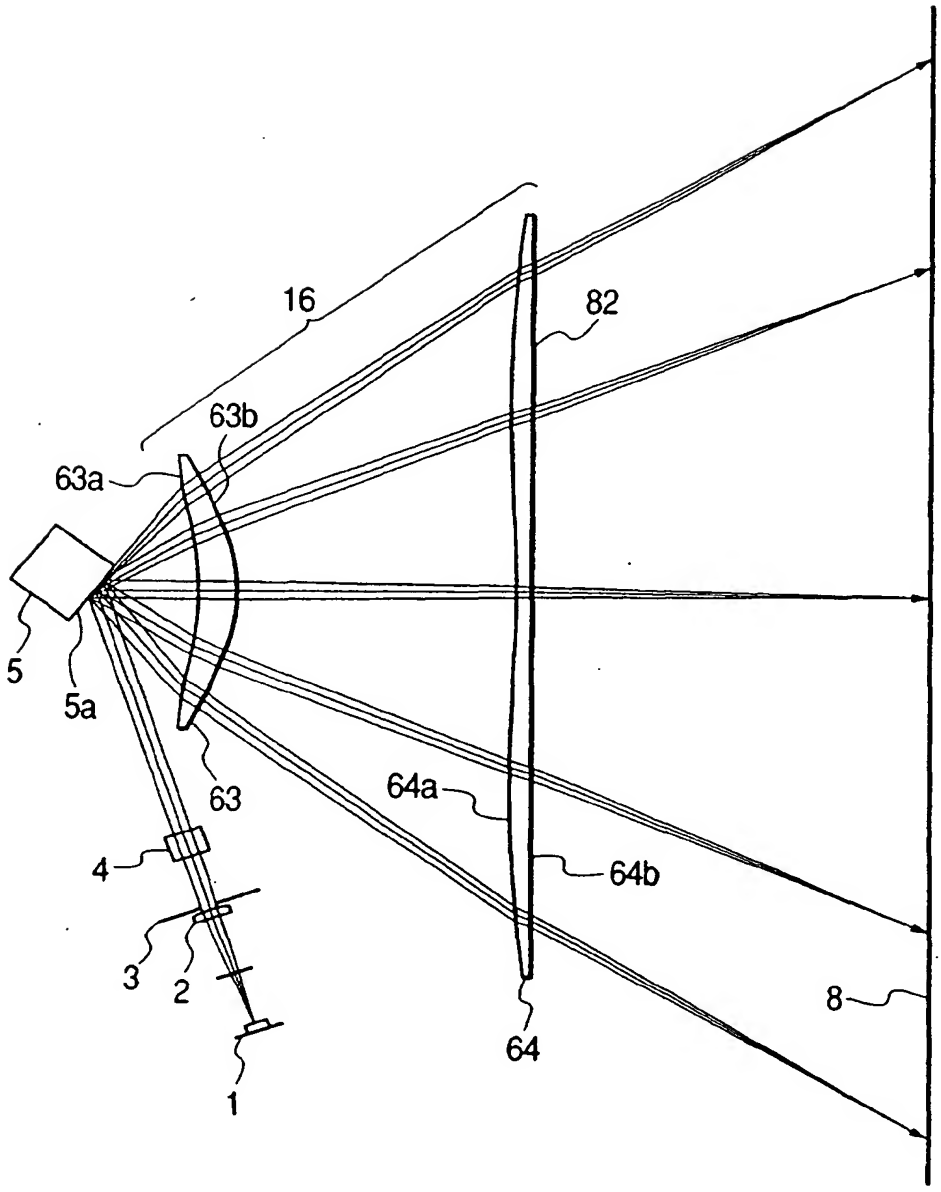

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FIG. 7

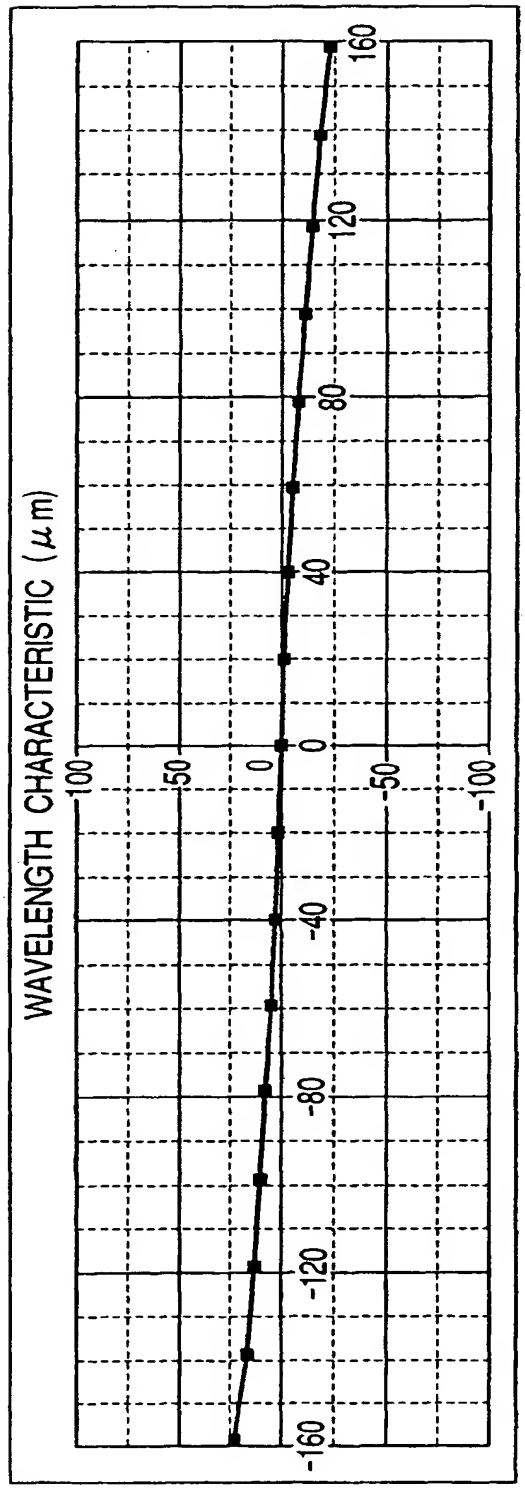

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FIG. 8

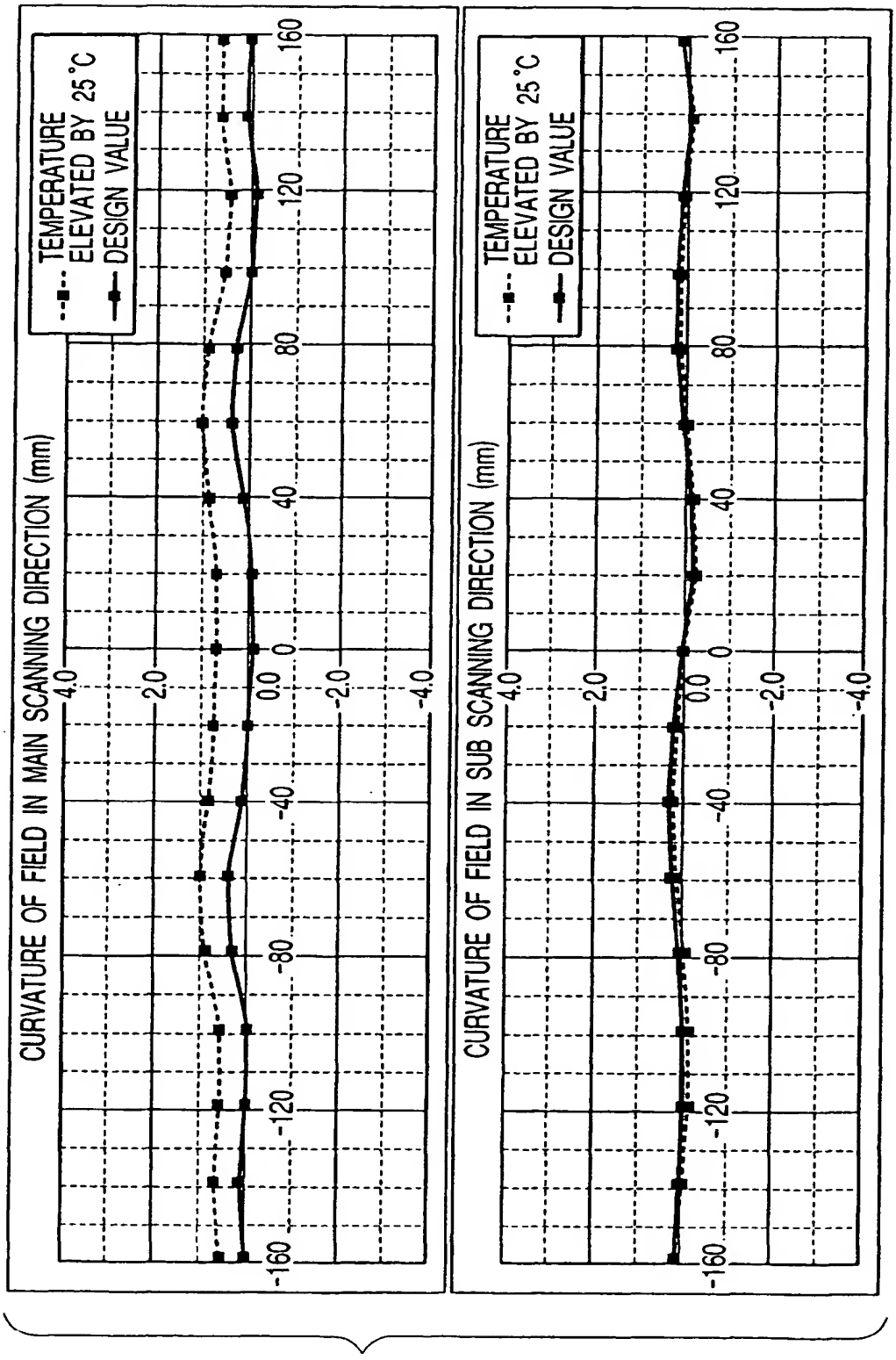

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FIG. 9

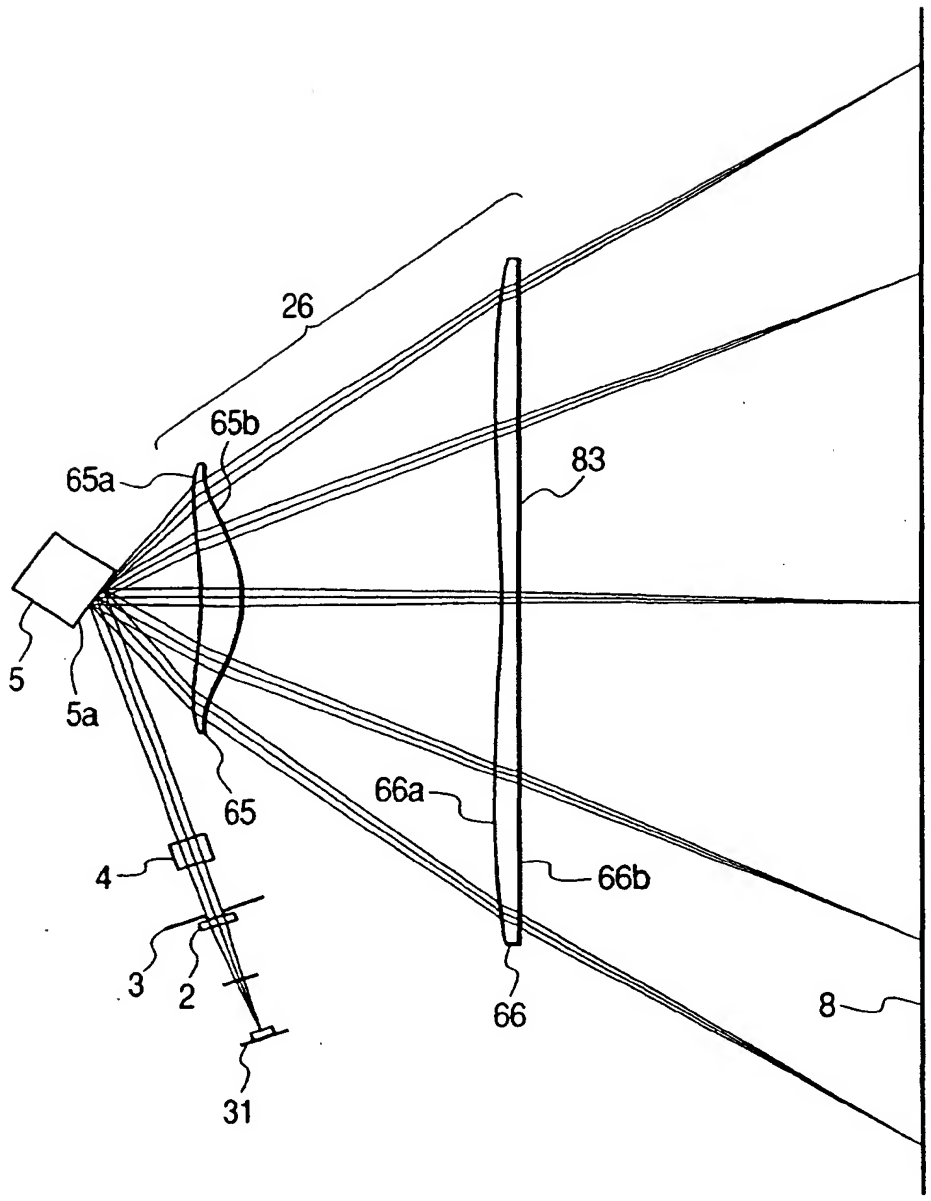

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FIG. 10

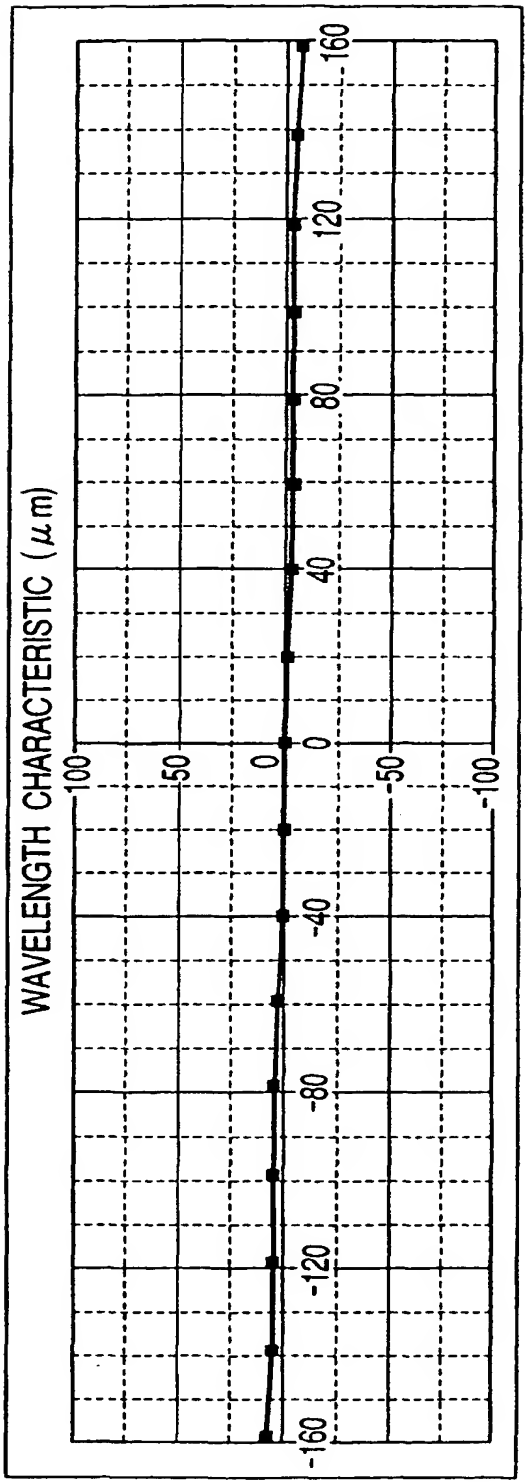

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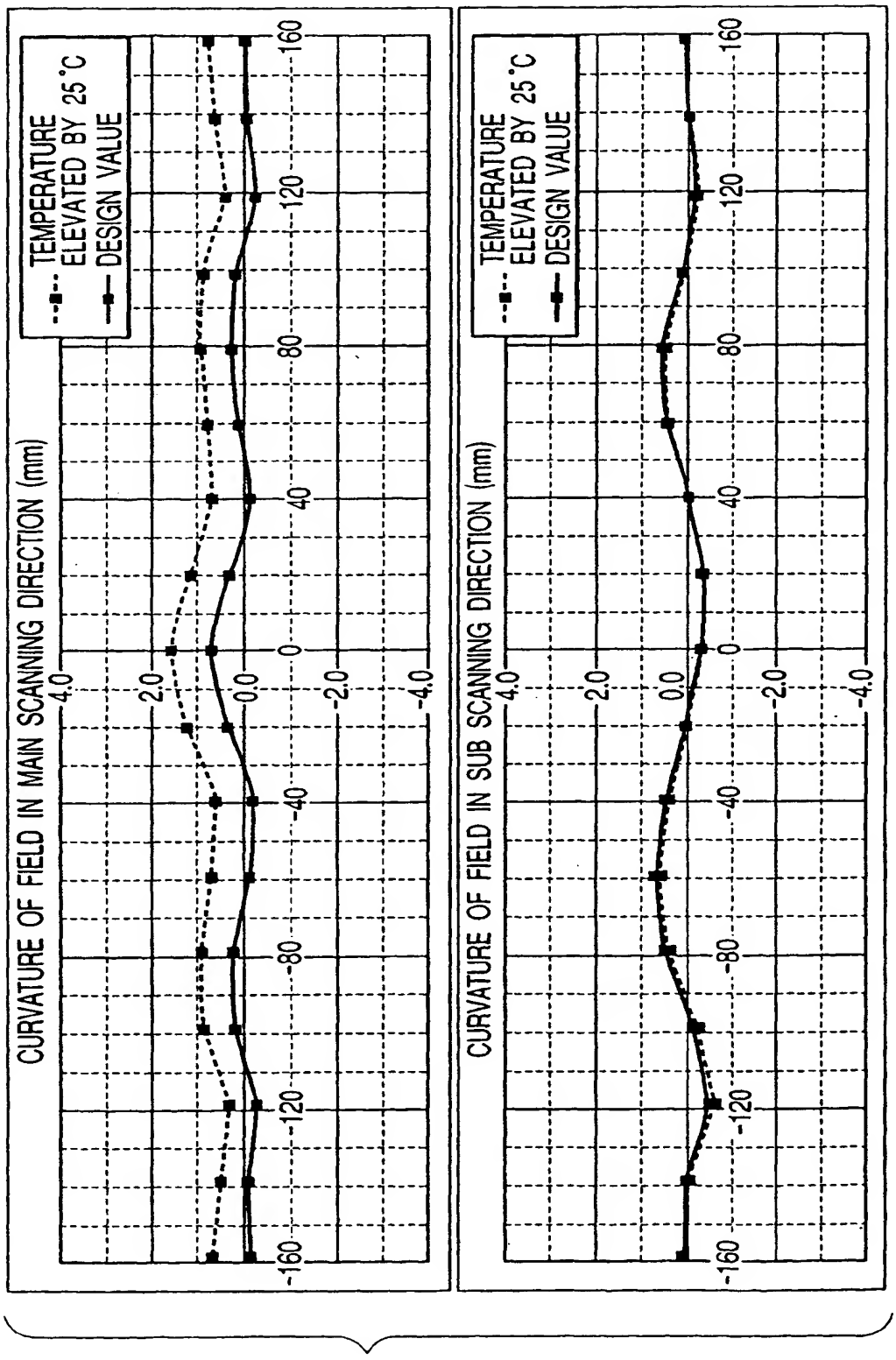
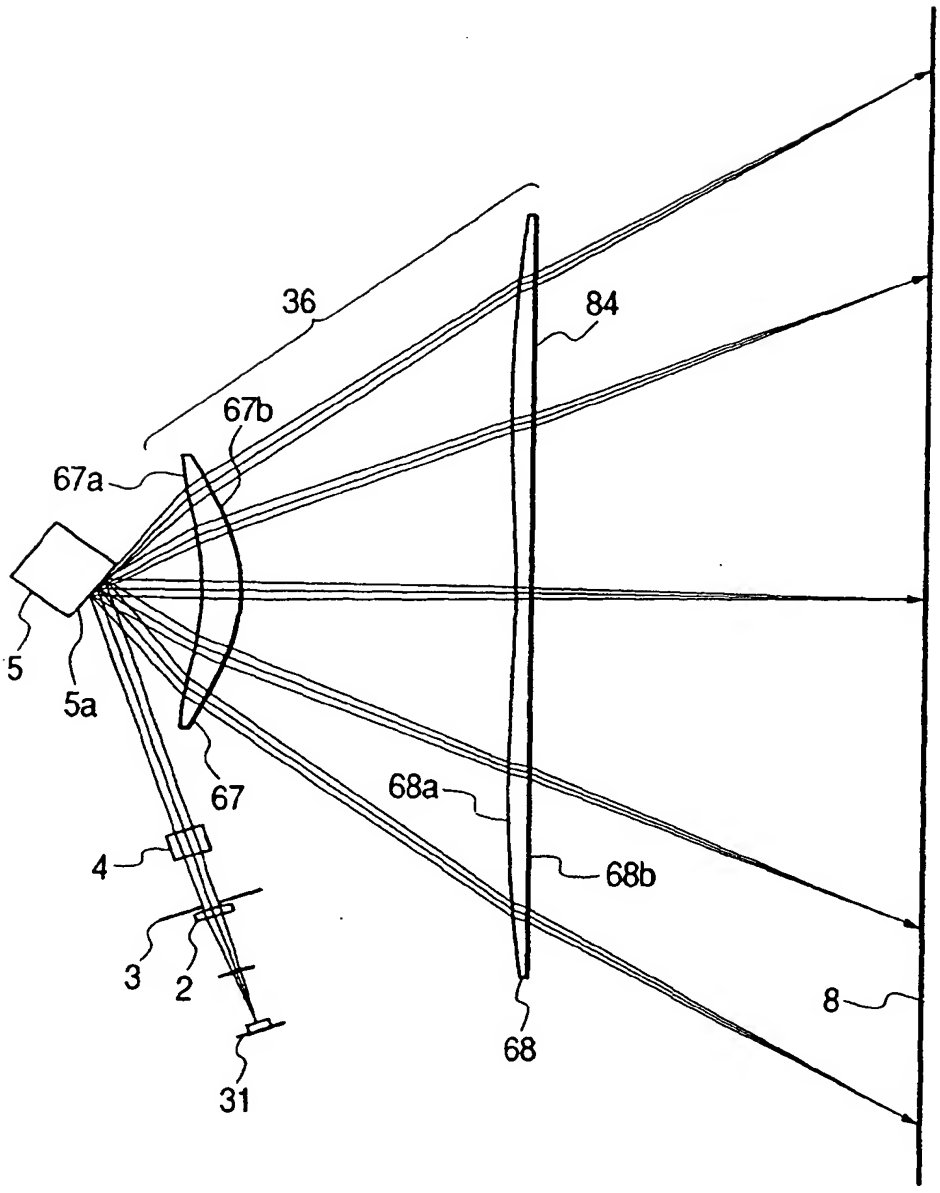
FIG. 11



NSDOCID: <EP___1122579A2_I_>

FIG. 12



:DOCID: <EP___1122579A2_I_>

FIG. 13

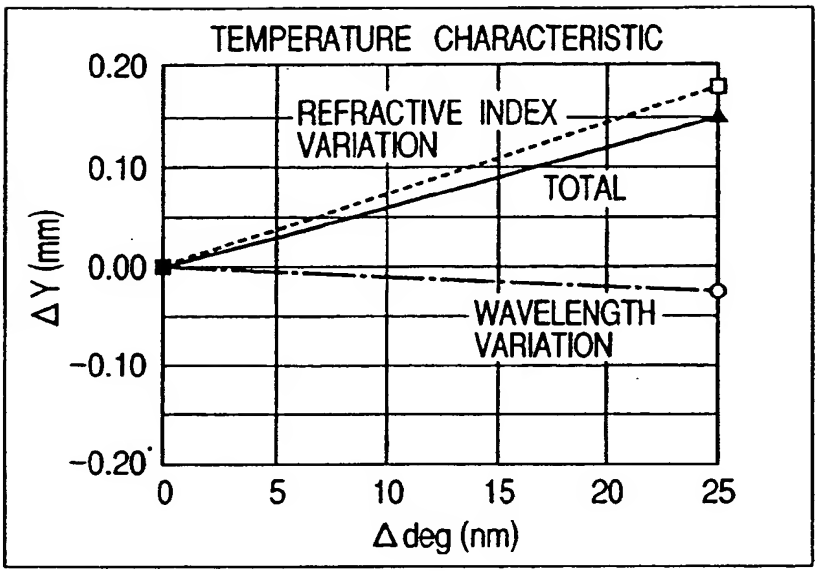


FIG. 14

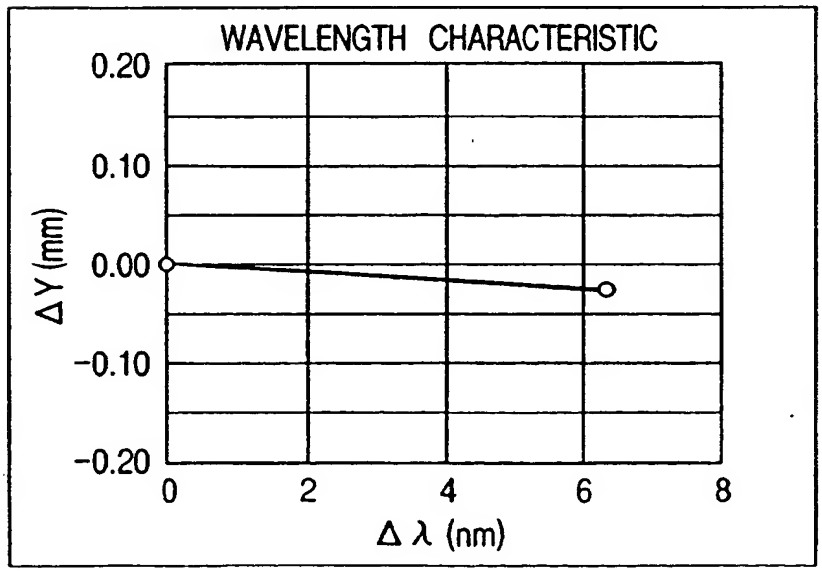


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FIG. 15

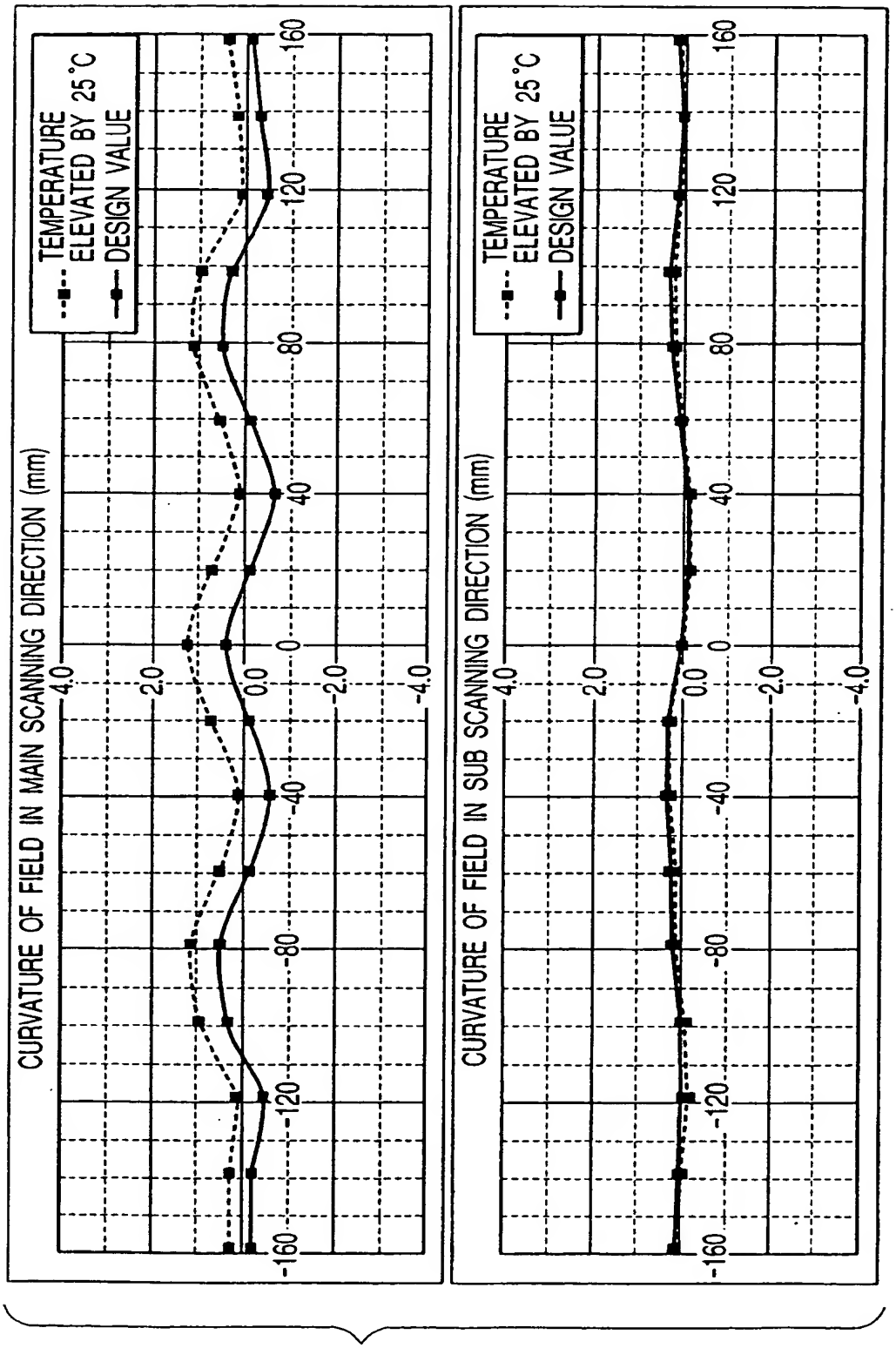

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FIG. 16

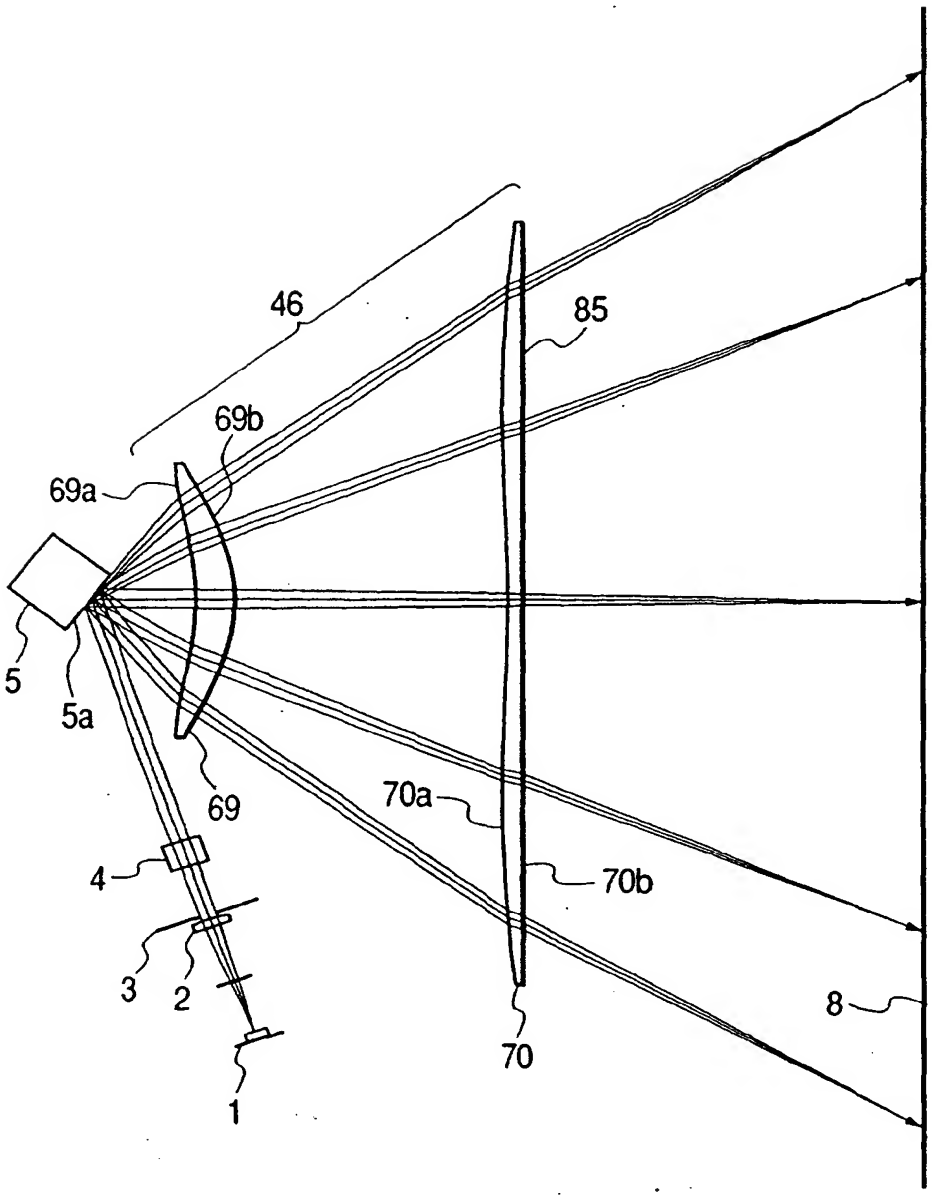

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FIG. 17

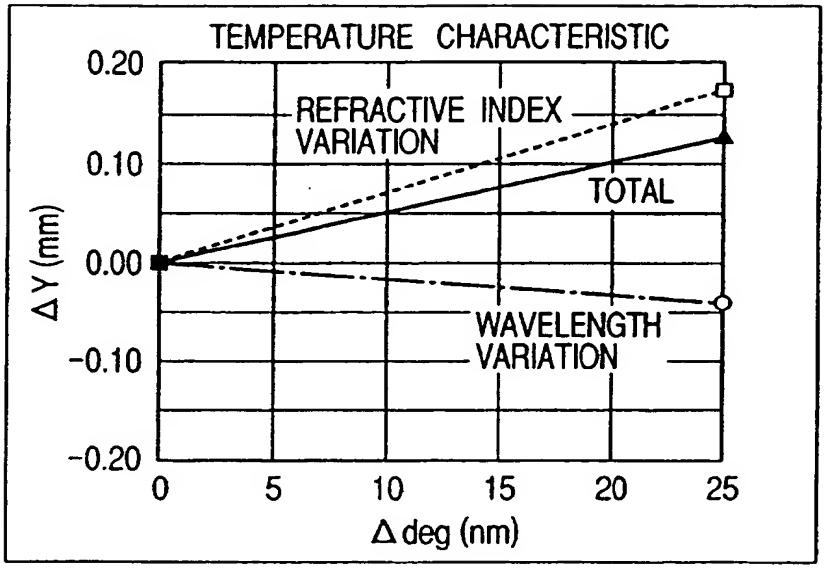

FIG. 18

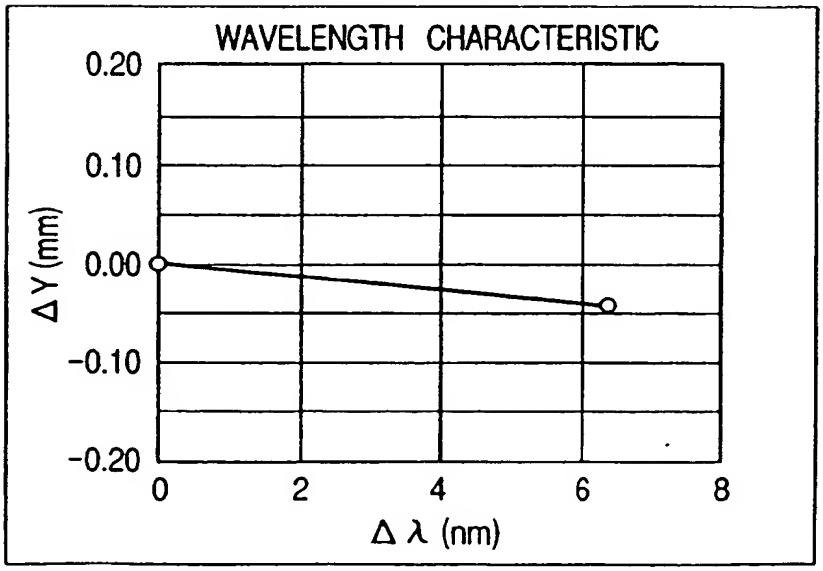

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FIG. 19

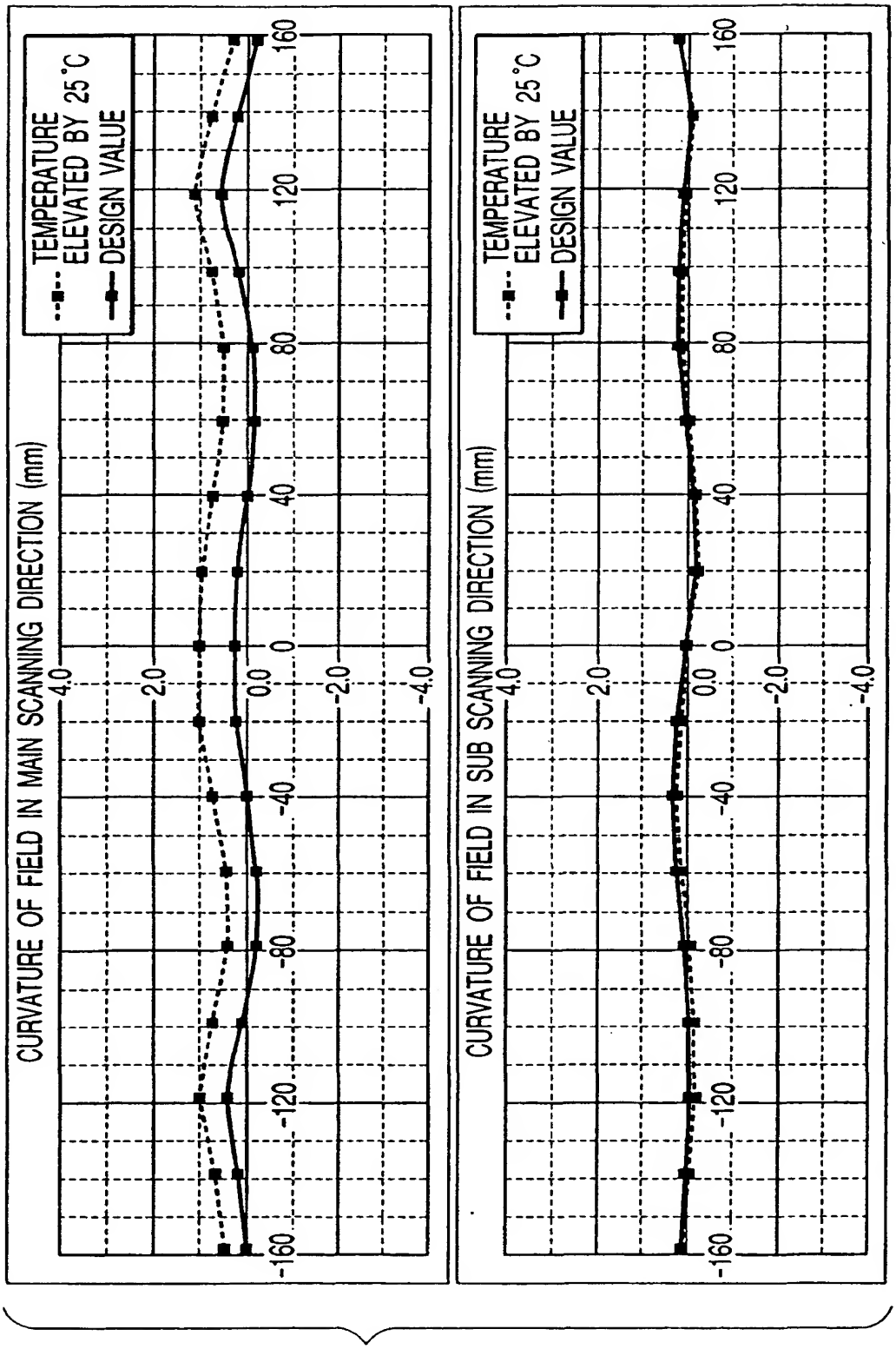

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FIG. 20

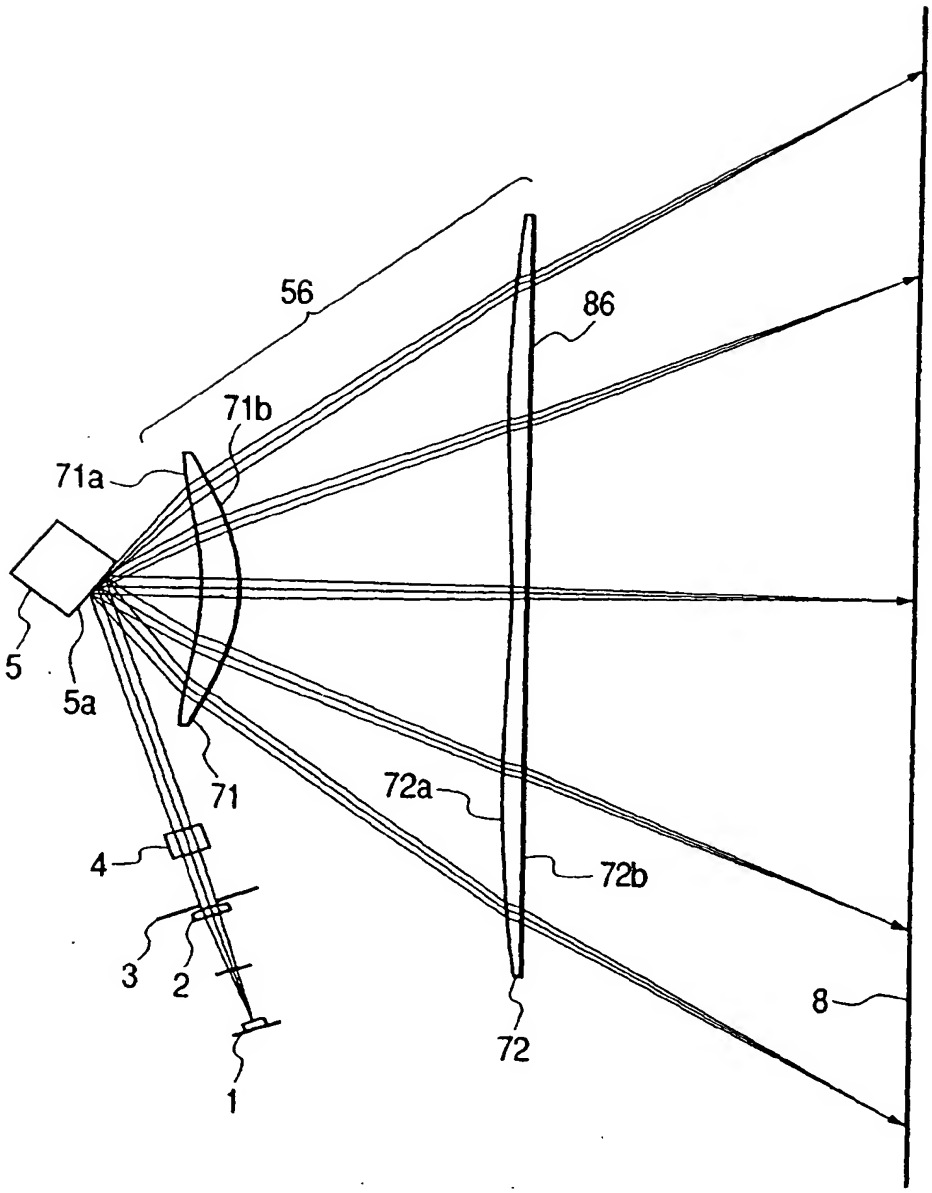

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FIG. 21

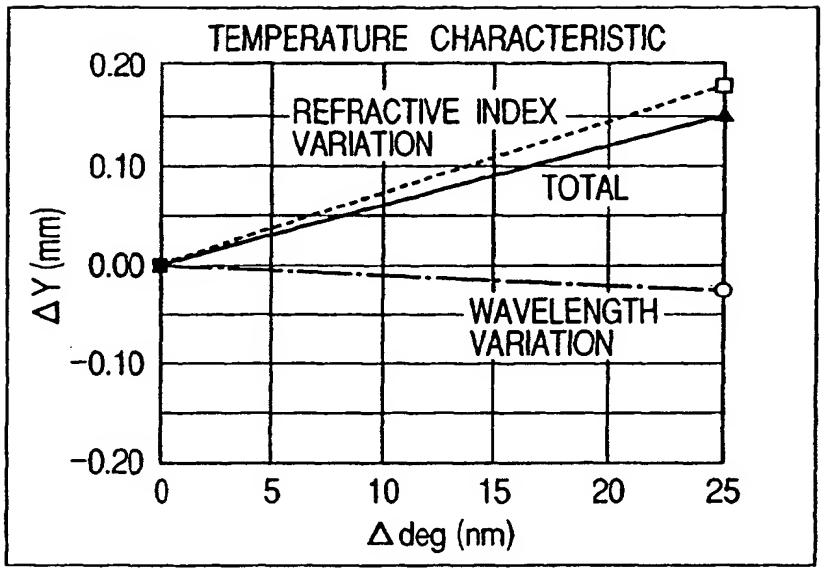

FIG. 22

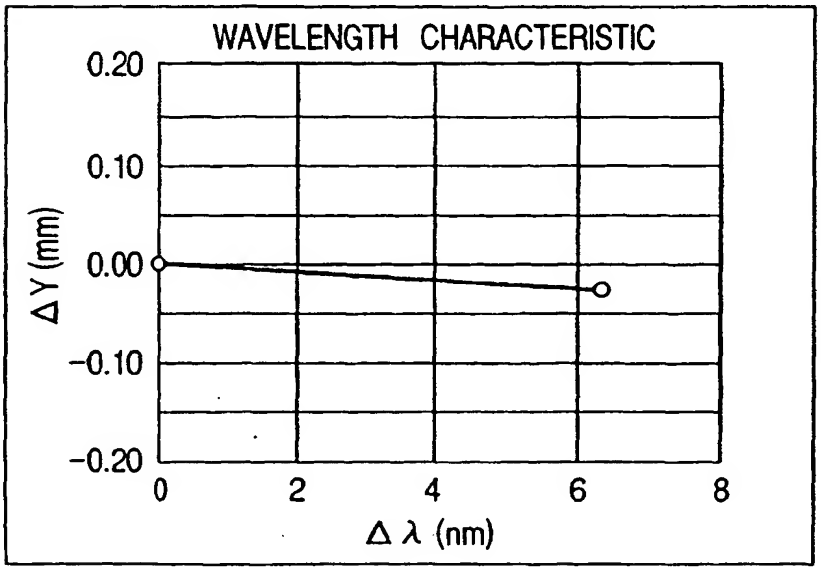

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FIG. 23

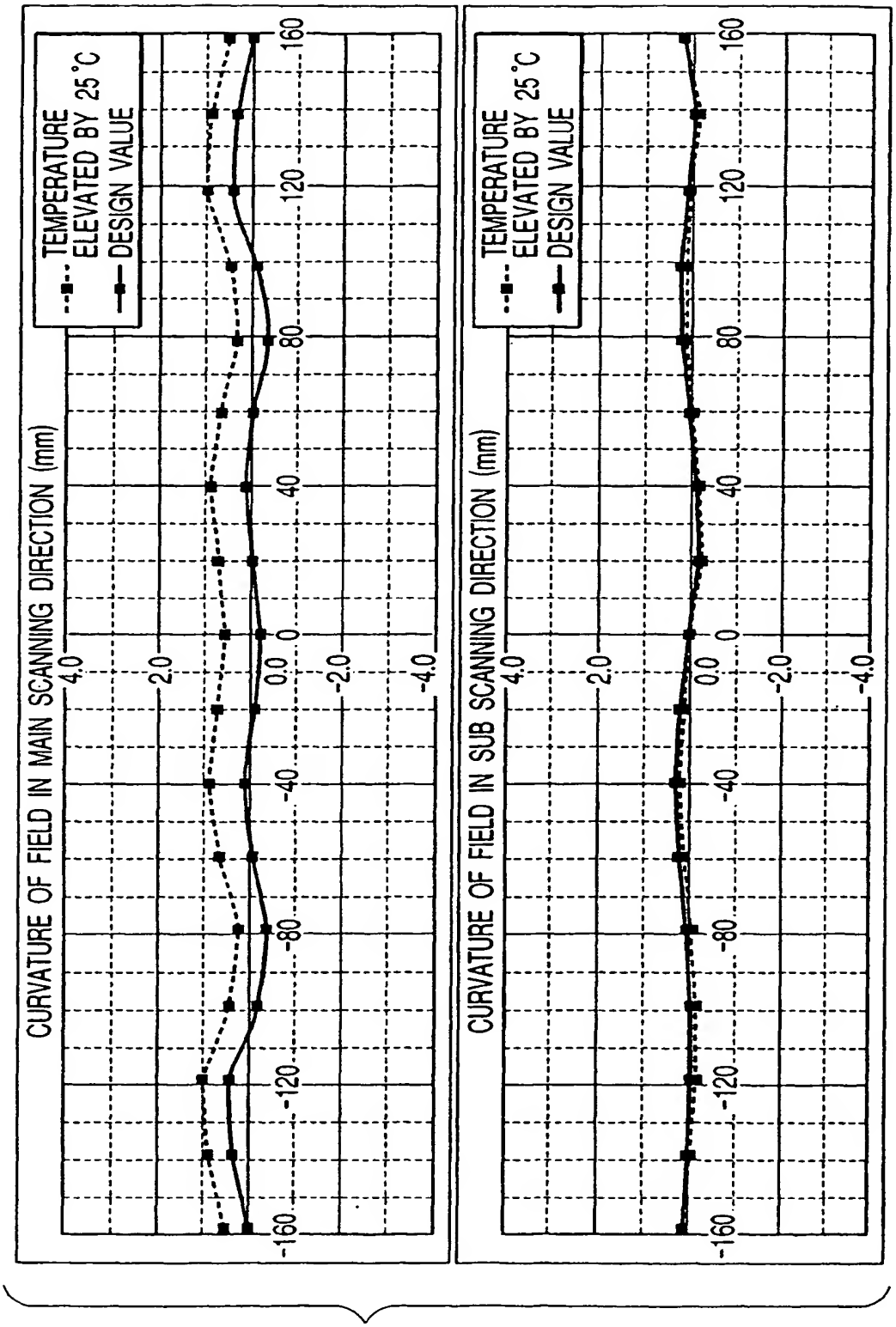

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FIG. 24

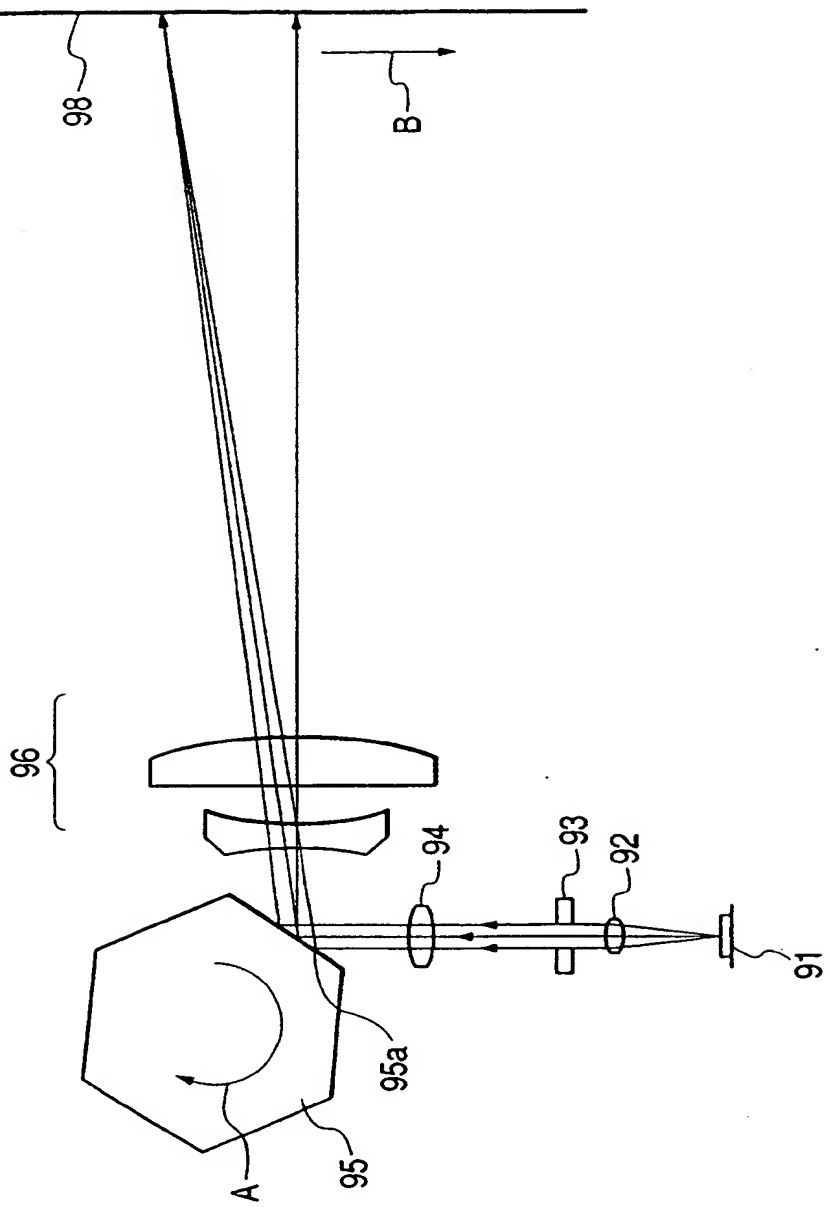

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FIG. 25

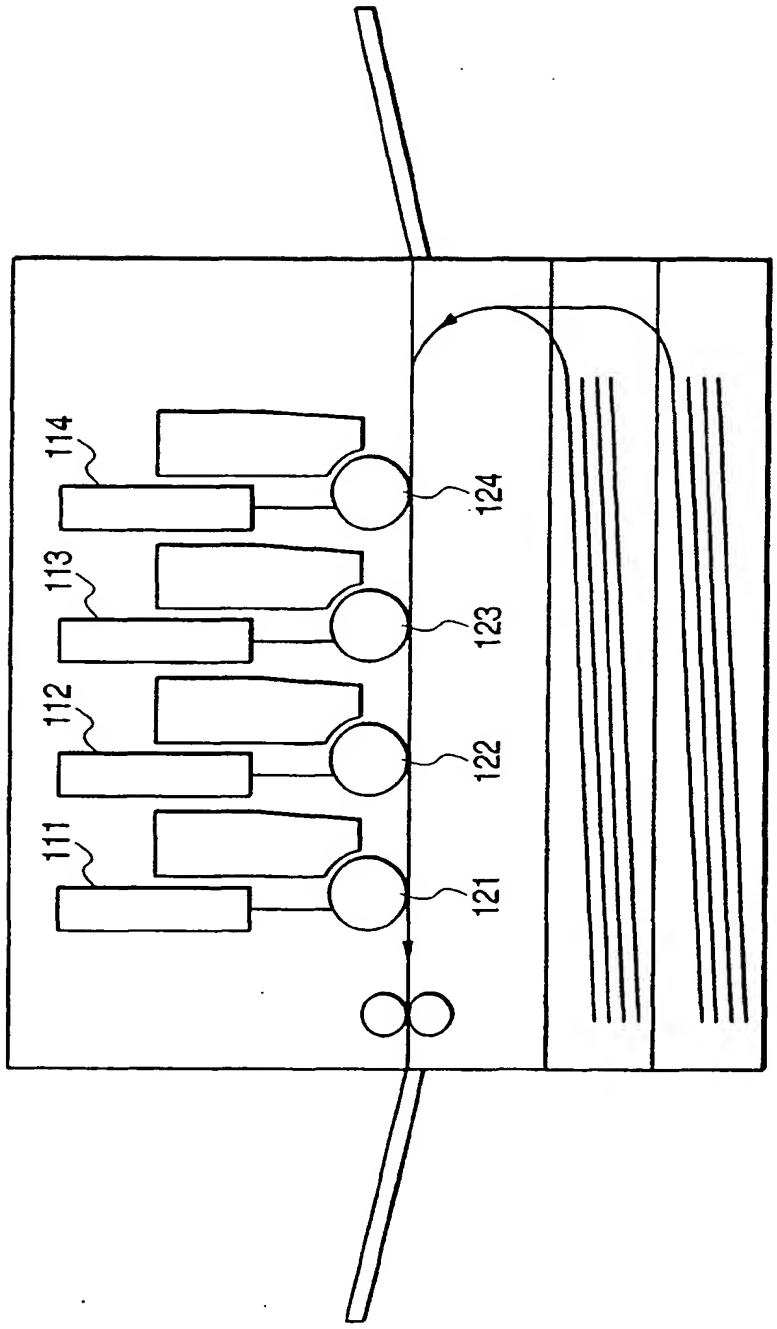

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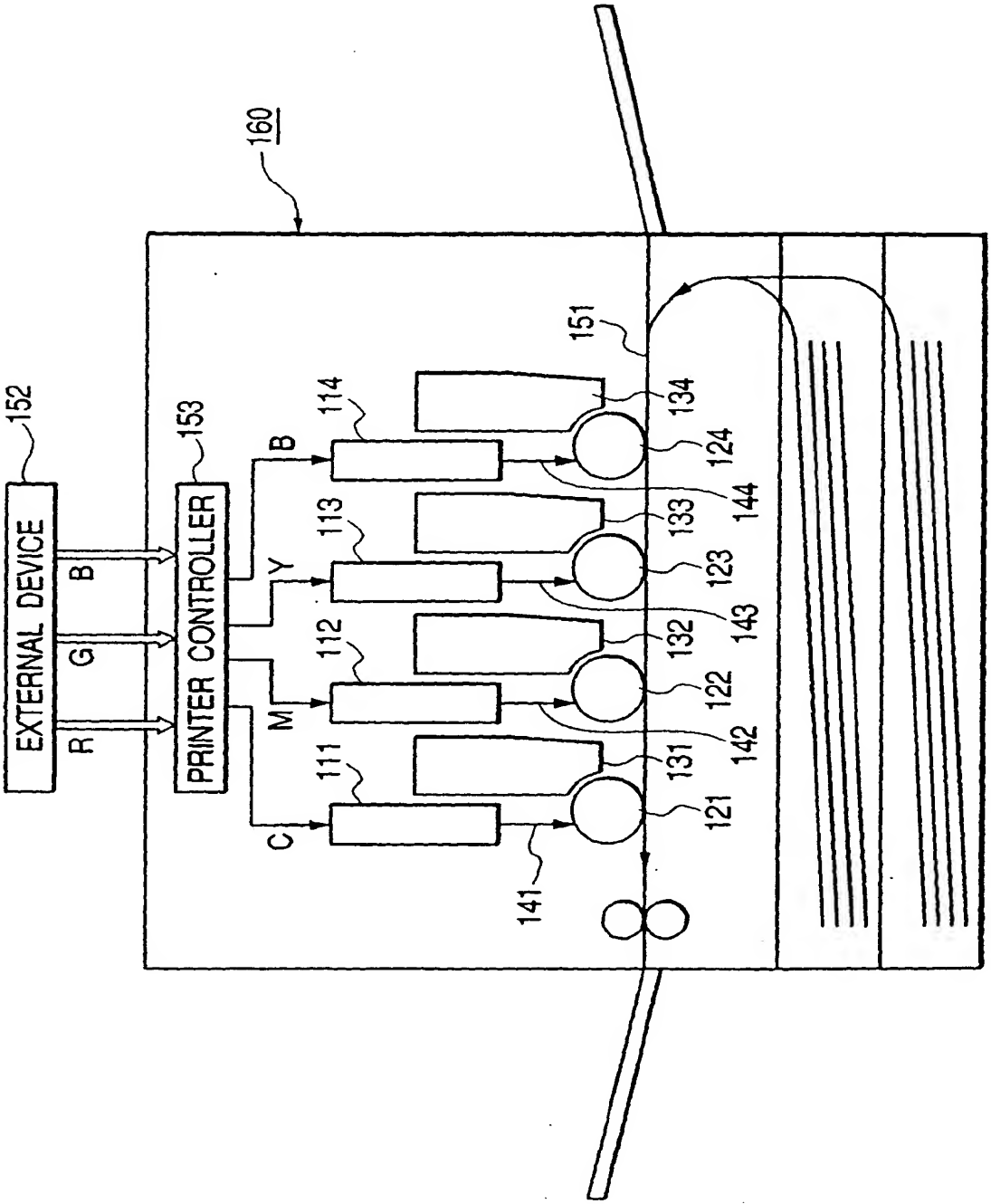
FIG. 26



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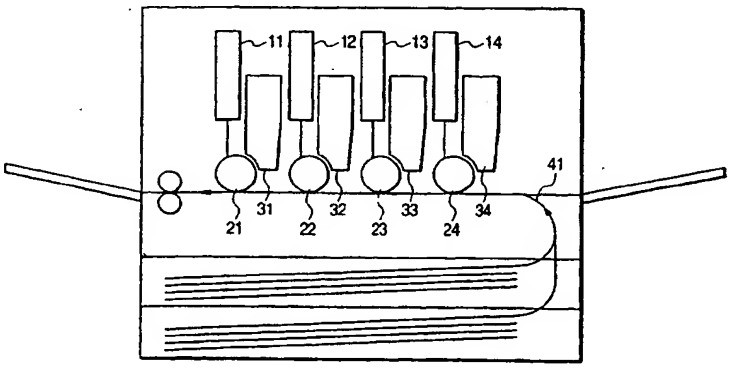
81245 München (DE)

(54) Scanning optical device and image forming apparatus

(57) As has been described above, this invention can achieve a scanning optical device and color image forming apparatus in which a refraction element and diffraction element are used as the scanning optical element of a scanning optical device, the powers of the refraction element and diffraction element are set such that an imaging position deviation in the main scanning direction caused by a wavelength variation along with the environmental fluctuation of the scanning optical device and an imaging position deviation caused by the refractive index variation of the material of the scanning optical element are set to opposite directions at the two ends of an effective image region (effective scanning region), thereby reducing an imaging position deviation caused by an environmental fluctuation, and at the same time an imaging position deviation caused by a wavelength variation not accompanied by any environmental fluctuation is also set to a desired value or less, thereby implementing a scanning optical device resistant to a wavelength fluctuation or environmental fluctuation, and in which images are recorded on a plurality of image carriers (photosensitive drums) using a plurality of scanning optical devices, thereby implementing with a simple arrangement at low cost a color image forming apparatus which is almost free from misregistration between colors caused by a wavelength fluctuation or environmental fluctuation and almost free from density nonuniformity between colors.

FIG. 1



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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 10 1721

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X Y	EP 0 827 004 A (CANON KK) 4 March 1998 (1998-03-04) * abstract * * figure 4 * * page 2, line 7 - page 4, line 52 * * page 5, line 57 - page 9, line 9 *	1-5,7, 9-12 8	G02B26/10 G02B26/12 G02B27/00
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X	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 13, 30 November 1999 (1999-11-30) -& JP 11 223783 A (CANON INC), 17 August 1999 (1999-08-17) * abstract * -& EP 0 935 153 A (CANON KABUSHIKI KAISHA) 11 August 1999 (1999-08-11) * figure 7 * * paragraph [0043] - paragraph [0050] *	1-7, 10-12	
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G02B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	11 August 2003	Windecker, R

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